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ON THE DETERMINATION OF THE FLOOD DISCHARGE OF RIVERS AND OF THE BACK-WATER CAUSED BY CONTRACTIONS.

By WILLIAM R. HUTTON, Member A. S. C. E.

READ DECEMBER 21ST, 1881.

WITH DISCUSSION BY THEODORE G. ELLIS, ROBERT E. MCMATH, AND WILLIAM R. HUTTON, Members A. S. C. E.

The determination of the flood discharge of rivers from data long previously obtained, is not unfrequently required of the engineer. So long as the flow is confined within the river's banks, the ascertainment of the discharge is easy, as the sections and slopes are generally tolerably well defined, and the usual laws of the movement of running water apply with reasonable approximation. But when the river passes its banks and overflows the surrounding country, all such rules generally become useless. The obstructions caused by trees, bushes, houses, fences, crops,

&c., hinder the flow and cause eddies and cross currents. The varying directions of the currents in different parts of the stream, the bodies of dead water, the return currents flowing in some cases up stream, all combine to render utterly unreliable any attempt to ascertain the discharge by computation from the cross-sections and surface slope. The variety of opinions and methods upon this question among engineers is well shown by the evidence of the experts in the "Elmira crossing case," a suit which on this account has attracted the attention of engineers, and more especially of some members of the Society, at whose request the following statement is introduced, the writer having been employed as expert on the part of the Lackawanna Company :

The New York, Lackawanna and Western Railroad sought to cross the New York, Lake Erie and Western, over grade, at Chemung flats, about 10 miles below the City of Elmira. The latter road at this place lies upon the southern side of the valley of the Chemung River, at a grade scarcely higher than the level of the ordinary annual floods of the river, and has often been damaged by the higher freshets recurring every few years.

The selected route of the Lackawanna road, after passing over the Erie, crossed obliquely the valley of the Chemung by means of the following constructions :

1. A bridge of 3 spans of 150 feet each, if measured on the centre line of roadway, but only about 60 feet if measured normal to the line of piers. The obliquity was so great that the lower end of an abutment or pier was 60 or 70 feet above the up stream end of the pier next to it on the south. This bridge crossed a high water channel of the river known as Parshall's Cove, and was known as the "Cove" bridge.

2. An embankment, 3 600 feet in length, and from 14 to 27 feet in height, across the flats on the south side of the river.

3. The Chemung River bridge of 4 spans, each 150 feet long, oblique to the line of roadway 70°, or 20° from a perpendicular.

4. A temporary pile trestle, 750 feet in length.

5. An embankment, 10 or 12 feet high, extending to the higher ground on the north side of the valley.

The valley of the Chemung at and above the crossing is from half to three quarters of a mile in width, quite irregular in its direction and in form, and through it the river winds, sometimes on one side, and sometimes on the other, in a bed from 400 to 600 feet in width.

The area of the water shed of the stream above the site of the crossing, is about 2 800 square miles.

After the official filing of the map and description of the Lackawanna route, the Erie Company, early in 1881, made ineffectual efforts to procure a change of the line by means of a commission appointed for the purpose by the courts, which, however, confirmed the recorded location. Later in the year the Lackawanna road applied for a commission to arrange the crossing and assess the amount of the damages to be paid therefor.

This commission met in August, adjourned to the 20th September, and from 25th September to the 4th October, and finally completed its work and made its award, on the 3d of November last.

The crossing was refused, and resisted by the Erie Company on the ground chiefly, that the construction of the Lackawanna railroad would increase the height of the flood waters above the crossing, and render the floods more than ever injurious to the Erie road, both by damage to its roadbed and by delaying the movement of its trains.

The hydraulic experts were, therefore, called upon to testify as to the increased height to which the flood waters would be raised by the proposed Lackawanna works.

This increased height, depended primarily upon the quantity of water carried by the river in floods, and therefore that quantity became the principal subject of discussion, and gave rise to conflicting opinions, and widely differing results.

The substance of the evidence, expert and other, bearing upon these points will stated as briefly as possible.

It was shown by the evidence offered by the Erie that the flood of March, 1865, was the highest known, at which time the entire valley was submerged from side to side, the depth of water on the flats at the place in question being in places 12 and 14 feet. Flood marks were shown, and their levels and distances given, which indicated a surface slope of 0.000 607 and 0.000 72 for 2 800 and 2 400 feet, and average slopes for 4 or 5 miles of 0.000 757. Cross sections of the flood were taken near these marks showing areas of about 24 000, 27 000, and 39 000, square feet. From these data differing results were obtained by the several experts summoned by the Erie road, varying with the formula used for computation, and the area of cross section adopted. A calculation by means of the Chézy formula (then called the Downing-D'Aubuisson

formula), with the co-efficient of 100 as proposed by Downing, gave 189 000 cubic feet per second. [The formula is , $v = 100\sqrt{RS}$, the letters representing as usual, v the velocity, R the mean radius, and S the slope.] For a second computation, by means of the same formula and co-efficient, but in which the deep and the shallow portions of the cross section were taken separately, a method recommended by Prony, the result obtained was about 204 000 cubic feet per second.

A third, applying the original formula of D'Aubuisson [$v = 94.74\sqrt{RS} - 0.11$] to "such data as were furnished" him — a formula "made for different purposes from this, however, and only a sort of in-"dication to aid the judgment in arriving at the result * * * in "that way * * made the discharge 169 444 cubic feet per second" —which he "considered to be considerably above what the quantity "should be." * * * * * Then, looking at it in another way, he said that in the highest flood known on the Merrimac river, the greatest discharge was equal to a depth ¾ of an inch in twenty-four hours applied to the entire water shed. Computing it at the same rate for the Chemung, with a water shed of 2 770 square miles, the quantity would be "55 860 cubic feet per second."

"From the character of the water shed," he continued, "I should "have no doubt it" (the discharge) "would be a good deal larger here "* * * and the true quantity would lie somewhere between these "two results, which are very wide apart * * * I have no doubt but "that the first result is too high, and * * * the last result too low, "and the truth is somewhere between them. I could do nothing else "* * but take an average of these two * * the mean result of "which is 112 652 cubic feet per second." * *

On the part of the Lackawanna railroad, it was claimed, first: that a comparison of the foregoing quantities referred to the water shed of the Chemung River, with the maximum flood discharges of other rivers of known drainage area, indicated plainly that these quantities were by far too large. The Potomac was cited with an area of about 11 000 square miles, and a flood discharge of less than 200 000 cubic feet per second, and the Kanawna with a drainage of nearly 9 000 square miles, discharging 118 000 cubic feet.

It was thence deduced, first: that the valley at the site of the crossing was not a proper place to furnish the data for a computation of discharge —that the varying direction of the main river channel, which carried

nearly half the entire flow, winding through, crossing and recrossing a valley whose general direction was nearly straight, its banks fringed with trees, the surface of the valley (or plain) obstructed by masses of woods and detached trees, and to some extent by houses, fences and the like—would so far hinder the flow of the water, and increase its surface slope, as to render any computation valueless, which was based upon measurements made at that place.

It was shown by evidence that in the City of Elmira definite flood marks for the freshet of 1865 could be obtained at a point where the channel was straight, regular and unobstructed, and suitable for measurement observations; and it was assumed that the discharge at the site of the crossing would be to the discharge at Elmira in proportion to the drained areas at these points, respectively.

It was also urged that the Chézy, or so-called Downing-D'Aubuisson formula, as well as that of D'Aubuisson, has been proved by more recent experiments to be incapable of correctly representing the flow of water in open channels, and that their results were not worthy of confidence—that the experiments of Darcy and Bazin, Humphreys and Abbott, those reported by Kutter, and others, showed that if the form of the Chézy formula was adopted, no one co-efficient would apply to different cases in which the conditions were not the same—conditions entirely neglected by the older hydraulicians.

The Kutter formula was claimed to represent, with the best attainable accuracy, the results of all experiments on flowing water in open channels; and its application to the Elmira observations gave for the discharge 72 815 cubic feet per second. It had, however, been proved by the testimony in the case, that the river overflowed its banks above Elmira; that the water gathered behind the embankment of the Erie Railroad which crosses the valley at that place, overflowed the embankment, cut it through, and ran down in another channel next the hills. It was, therefore, not included in the first computed discharge. Nor was there any way to measure it. As, however, when the embankment broke, the surface of the water in the pond above it was lowered, the outflow was evidently greater than the inflow, and the discharge through the break (of known dimensions) was in excess of the real quantity overflowing at the point referred to. Adding this quantity (6105 cubic feet) to the former, and increasing it in proportion to the greater drainage area at the site of the crossing, 91 547 cubic feet per second was claimed by the Lackawanna

Company to be the true, or rather the possible maximum discharge of the river in the flood of 1865. On rebuttal, however, it was proved by the Erie Company that a further quantity had escaped from the river in Elmira immediately above the place of measurement, and was to be added to the 91 547 cubic feet; and by cross-examination of the witness by the counsel for the Lackawanna, it was developed that this quantity flowed about one foot deep across a street 700 or 800 feet in length. There was no way in which any computation of the quantity could be brought before the Commission by the Lackawanna side, and none was made by the Erie, but the former company *attempted* to bring out the fact that if the street were treated as a weir, and the quantity flowing across it were computed by the formula for the discharge of weirs, the result would be larger than if calculated in any other way—that increased by the proportion due to greater water-shed at the crossing, it would be 3 500 cubic feet, and that the total flow of the river at the crossing, would be increased by it to about 95 000 cubic feet per second.

It was, moreover, stated by witnesses produced by the Lackawanna Company that during the height of this flood, the State dam across the river at Corning, or rather the guard bank connecting the dam with the high ground, was overflowed and broken through, and that the water in the pool fell in consequence 4 feet in about 1½ to 1¾ hours, forming a wave which, as observed upon the piers of a bridge, was 4 to 6 feet high 1 000 feet below the dam; that a sudden rise of about 2½ feet took place at a point some miles below, and of 2 feet at Elmira, 18 miles from the dam. These statements were contradicted by witnesses in rebuttal, but are given as the bases of certain hypotheses which were introduced.

The Erie witness upon this point testified that the break in the embankment was only 10 or 12 feet wide; that the dam was drowned out, the water on both sides being about level with the top of the guard bank, that the water in the pool did not fall after the break, but was somewhat higher later in the day.

The hypothetical cases submitted to the experts by the counsel on each side were each based upon the testimony presented by themselves, respectively.

The Lackawanna Company asserted, in general terms, that the effect of the rupture of the Corning dam, as described by its witnesses, would be felt many miles below, and guided by the evidence, and by the general theory of waves, and observations upon their formation and propo-


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NEW YORK LAKE ERIE & WESTERN R
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A
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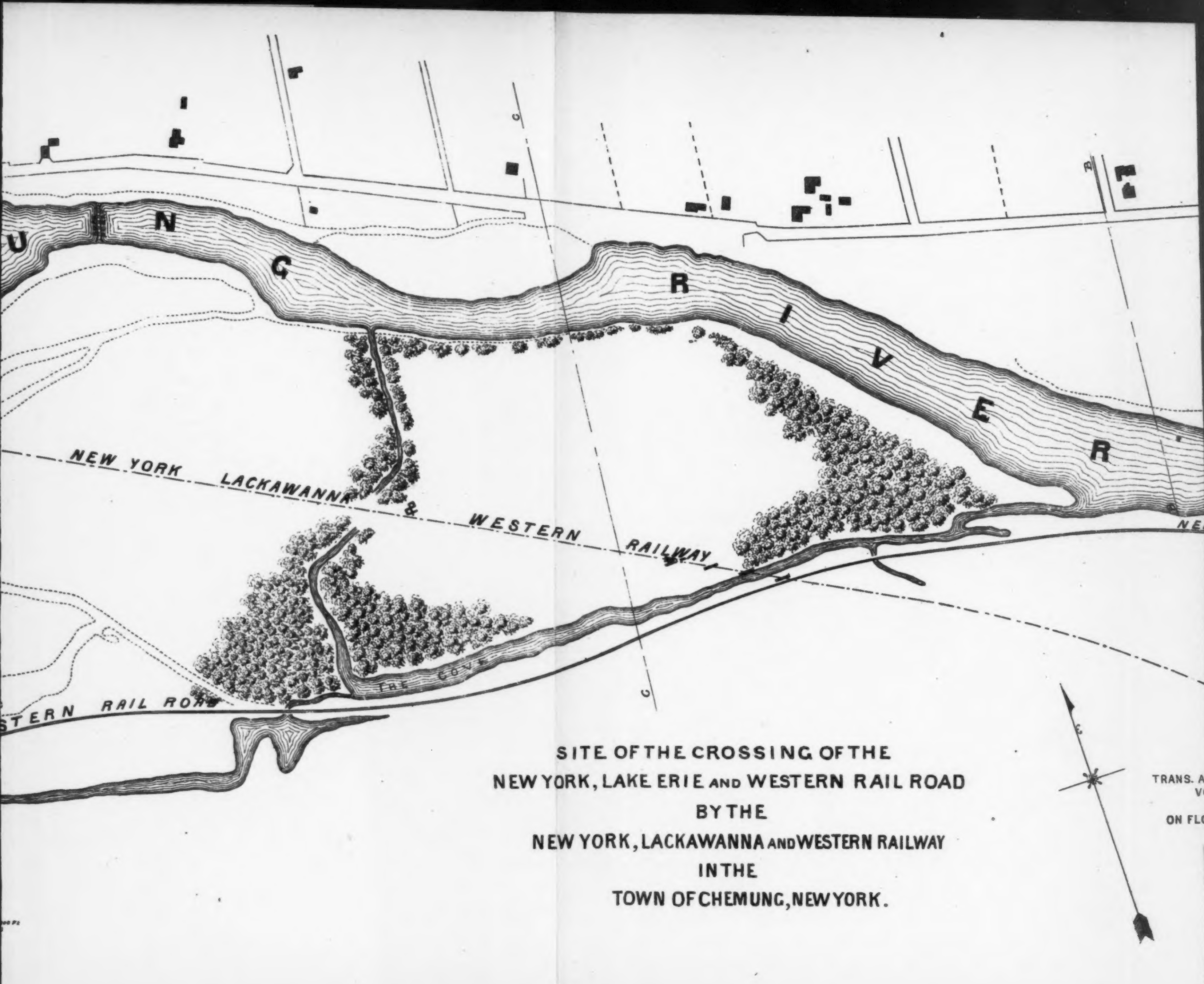
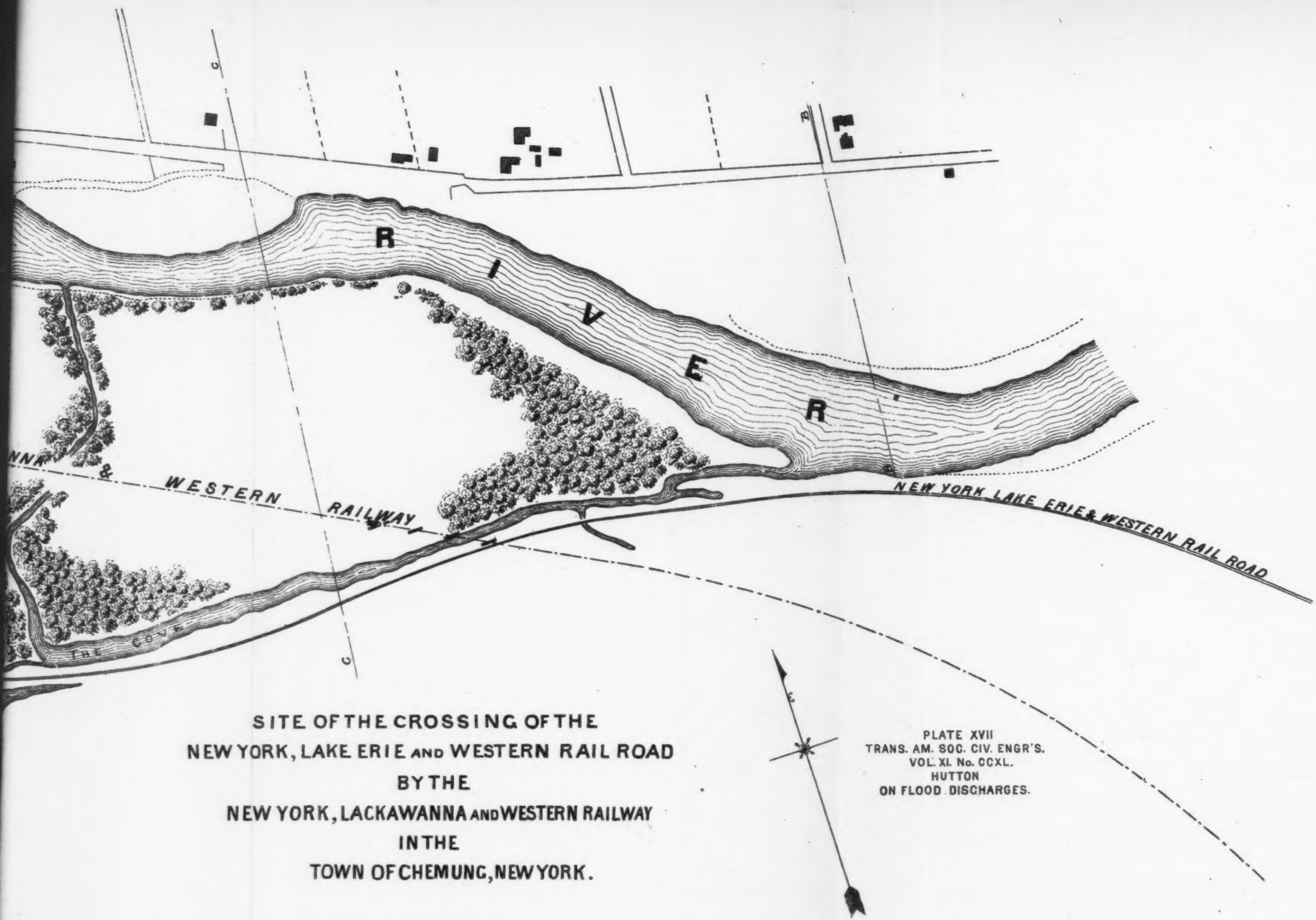


SITE OF THE CROSSING OF THE
NEW YORK, LAKE ERIE AND WESTERN RAIL ROAD
BY THE
NEW YORK, LACKAWANNA AND WESTERN RAILWAY
IN THE
TOWN OF CHEMUNG, NEW YORK.



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gation ; supported also by the observed facts of an artificial wave created in aid of the navigation upon the river Yonne in France—a wave formed by the discharge of waters impounded in advance upon the lateral streams—the *opinion* was expressed that at the site of the crossing the additional height of flood due to the wave caused by the failure of the Corning dam, would be from six to twelve inches. It was noted that the navigation wave referred to with a primitive height of 3 feet, reduced to about 2 feet at the mouth of the Yonne, its junction with the Seine, maintained itself with a diminishing height as far as Paris, 60 miles, at which point its height was about a foot.

The experts on the part of the Erie were positive that the rupture as described by the witness called by their side of the case, would have no appreciable effect upon the height of the flood surface 28 miles below. Considering the case as described by the Lackawanna witnesses, it was thought the effect would be to increase the flood height by not more than two inches. But in speaking of the hypothetical case put by the the counsel for the Lackawanna, as to the probable effect of a rupture which should discharge from the pool *about* 40 000 000 cubic feet in 100 minutes, producing wave effects as before described, one of them estimated that the height of the wave at the crossing might be about a foot, adding however, that the case was an impossible one.

The formulæ for the height of backwater produced by a contraction, as used by the different experts, are nearly the same. They all give the head required to cause the necessary change of velocity in passing from the large section above the works to the contracted section, multiplied by a co-efficient of contraction, which is given by the older authorities as from 0.80 to 0.90, or from 0.70 to 0.95, depending upon the form of the starlings of the piers, and in a general way, upon the size of the openings.

The co-efficient of contraction was taken by some of the Erie experts at 0.80, which was considered by one of them not too low, although the pier heads were of good shape, because of the obstructions caused by the remains of coffer-dams about the piers, and perhaps for other causes.

All the experts assumed that the bridge openings were equivalent to others of equal size made in an embankment, crossing the valley about at right angles to its general course, omitting all consideration of the relative positions of the two bridge openings lengthwise of the stream.

On the part of the Lackawanna, the question was treated in the same

manner, although it was claimed that the shape of the approach to the Cove bridge justified a higher co-efficient, and that at this point the actual normal section should be used from the abutment to the bank of the Erie road, which would leave out of consideration the intermediate piers, although as one of these piers would be near enough below any section to affect the discharge through it, the obstruction due to one pier should be allowed for. It was also suggested that, as shown by Mr. Francis' experiments upon weirs, the contraction was dependent upon the number of piers, or of *ends* causing contraction, and upon the depth, and that the ordinary formula did not by any means correctly represent the conditions. The usual method, however, was used by the Lackawanna expert, with a co-efficient of 0.90, which was deemed to be authorized for the one bridge by the form of the approach, and by the great size of the openings of the other, exceeding that of any bridge from which co-efficients had been deduced.

The results of the various computations gave as the height of back-water due to the constructions, 4.3 feet, 2.3 feet, 1.67 feet and 1.33 feet, and by the Lackawanna computations, 0.568 feet.

The great difference between these figures is in part accounted for by the fact that the height of backwater varies with the square of the velocity, and consequently with the square of the quantity of discharge, and inversely with the square of the co-efficient of contraction. A double discharge would therefore quadruple the height of backwater, and the difference caused by using a co-efficient of contraction of 0.80, instead of 0.90, is as 64 to 81. The errors, therefore, of original computations are greatly magnified by the application of them to this case.

In addition, some of the computations for the Erie were made, counting the openings above the natural surface, while the Lackawanna supposed the earth under the openings to be cut down to the level of low water.

Various opinions were expressed by the experts upon the length of opening or water way in the Lackawanna embankment which would reduce the additional rise in floods to a merely nominal height so as to remove cause for objection on the part of the Erie ; but, it is believed, no calculations were made to determine the point, except one submitted by the Lackawanna, which showed that with an additional clear opening 300 feet wide, normal to the current, the backwater would be reduced to 3 inches in height.

The principal controversy in the case related to the use of the Kutter formula for the flow of water in open channels. It was claimed by the Lackawanna company, and, in fact, substantially admitted toward the close of the case, that while this formula might give very absurd results in certain hypothetical cases not included in the experiments upon which it was framed, it did correctly represent the result of those experiments and observations ; that these observations covered a wide range of streams and rivers, large and small, with steep slopes and flat ones, and that by a study of these examples, an engineer could select the case most nearly approaching his own, and find there a reasonably safe rule to guide his computations. On the other hand, it was urged by some that the exercise of judgment on the part of the engineer could not be dispensed with—that he must make such reductions from the results given by the Downing-D'Aubuisson formula as his judgment and experience alone might suggest, being without other recourse.

Extract from award of commission :

* * * "They deem it necessary to state their views in regard to the floods of the river and their effects, and the course of reasoning which has led them to their conclusions.

"The testimony shows the flood and flood marks ; the experts differed largely as to the effects to be produced on them by the works of the Lackawanna Company, but agree as to the rule by which it is to be computed. The differences in the results arise from three main causes, namely, the difference in the estimated volume of water, the assumed slope of the surface of the flood, and the co-efficient used to represent the sinuosities, roughness, slope, form and volume of the flood.

"The results arrived at by Mr. Francis, who was called by the Erie, and Mr. Hutton, called by the Lackawanna, come nearest to agreement, and if they had used the same volume of flood, their agreement in regard to the computed rise would have been much closer.

* * * * * * * * *

"Under these circumstances, the commissioners have caused calculations to be made by which they have formed the opinion that the volume of the flood of 1865 was about 100 000 cubic feet per second.

"And after making all allowance for the excess of that flood over all other known floods, and the effect of the break in the Corning dam during that flood, the commisioners have determined the amount of bridge-

opening and other provisions necessary, in their judgment, to prevent a materially increased rise in the floods of the river, by the construction of the Lackawanna works at the point in question.

"Applying their conclusions to the matter in issue, the commissioners award:

"1. The Lackawanna Company Railroad to cross the Erie by a single span of 55 feet at right angles to the abutments, and 20 feet above the outer rail of the Erie track to the lowest projection of the bridge. * * *

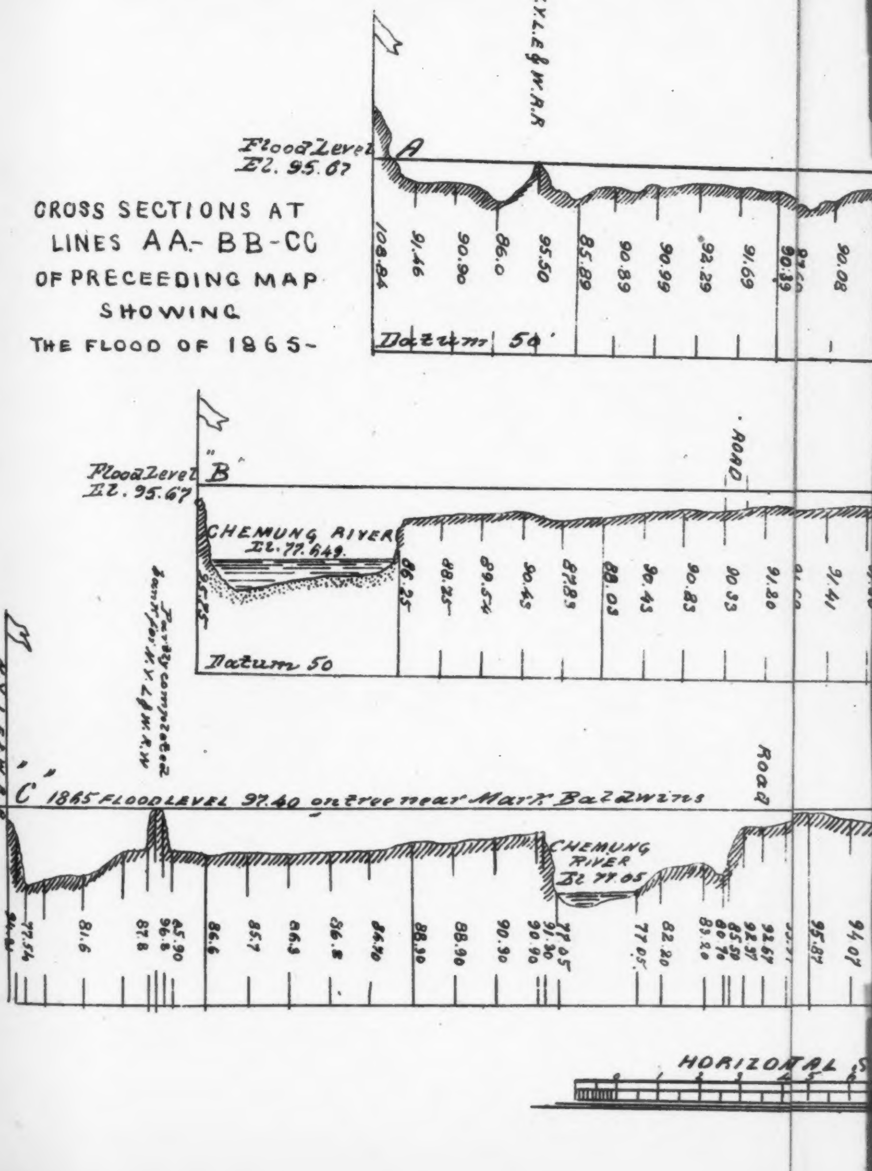
"2. Westerly of said river, bridging shall be constructed for a distance of 405 feet, in spans of not less than 135 feet."

The foregoing is a brief statement of the testimony and discussions introduced into the case. In reviewing, something more may be said upon the points involved.

And first of the Kutter formula.

During the progress of the case, of Ganguillet & Kutter it was said that "they made a general formula which they thought would cover all cases. That it had been tested by computing the discharge of the Mississippi, supposing its bed coated with smooth cement, and the result was a velocity twice as great as the observed actual velocity. This was thought to be manifestly absurd, and therefore, under all circumstances, the Kutter formula should be discarded for rivers. That this formula was based upon a certain amount of roughness in the bed of the stream, whether it be large or small, whether it is a mile wide or a foot, or whether it is deep or shallow; the character of the banks enters into it as a co-efficient. * * * Now in a very large river like the Mississippi, boulders of 10, 20 or 30 feet in diameter would be smooth bottom compared with the irregularities Kutter mentions in his formula. Although he has made a formula, it should not be taken for such streams as this, the Chemung, but for the streams from which it was derived, which is a peculiarity of all hydraulic formulæ. They are usually applicable to the stream they are derived from, and no other."

These statements are quoted at length because they indicate a common misconception of the Kutter formula. That formula was based upon all known experiments which had been reported with sufficient exactness. It does not recognize any theory or principle of running water. The aim of its authors was to find an expression which should represent, with a sufficient approximation, the results of the experiments before them. These observations covered a very wide range of cases and conditions, and it is rare


CROSS SECTIONS AT
LINES AA-BB-CC
OF PRECEEDING MAP
SHOWING
THE FLOOD OF 1865-
N.Y.L.E.&W.R.R
Flood Level A
El. 95.67
108.84
91.46
90.90
86.0
95.50
85.89
90.89
90.99
92.29
91.69
90.39
90.08
Datum 50'
Flood Level "B"
El. 95.67
CHEMUNG RIVER
El. 77.649.
ROAD
86.25
88.25
89.54
90.45
87.89
88.03
90.43
90.83
90.33
91.80
91.41
Datum 50
N.Y.L.E.&W.R.R
"C" 1865 FLOOD LEVEL 97.40 on tree near Mark Baldwins
Road
CHEMUNG
RIVER
El 77.05
77.54
81.6
87.8
96.8
85.90
86.6
85.7
86.3
86.8
86.70
88.90
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91.30
77.05
77.05
82.20
89.20
95.87
94.07
HORIZONTAL SC

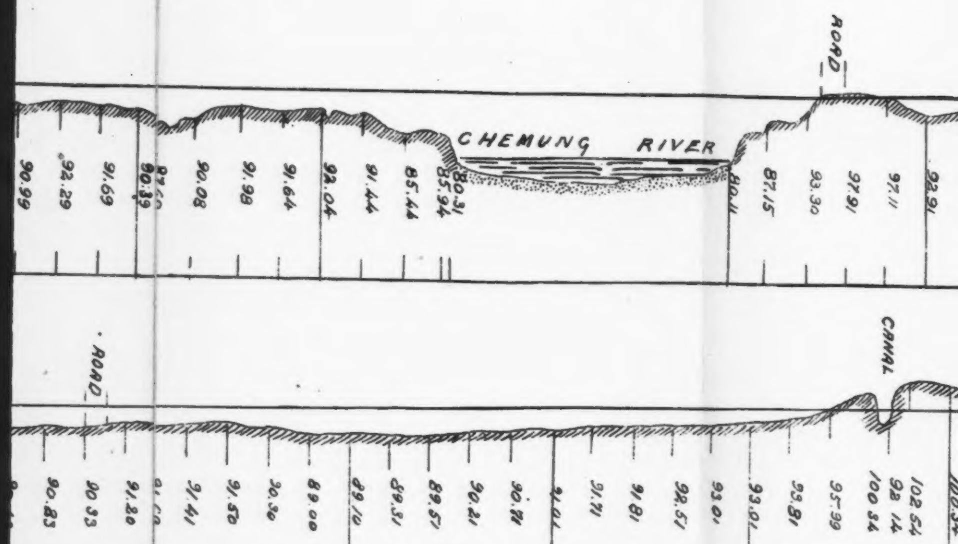
ROAD
CHEMUNG RIVER
ROAD
CANAL
Road
CANAL
HORIZONTAL SCALE
1000 ft
VERTICAL SCALE

PLATE XVIII
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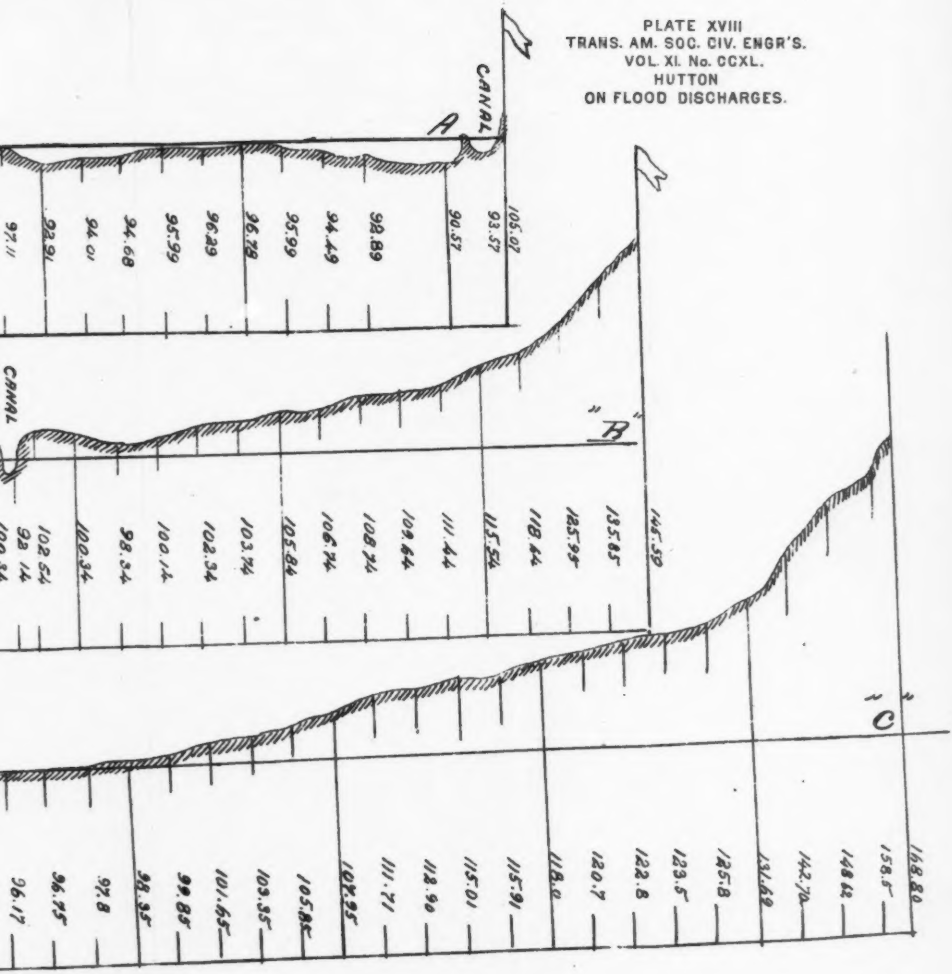

that a case will present itself in practice which will not have its counterpart among these experiments. Hence in this, as in all other engineering formulæ, a knowledge of the manner of constructing the formula and the data upon which it is formed are necessary to its intelligent application. And this also will explain the extravagant results of the formula when applied to the Mississippi River, supposed with a cement-lined bed. The observations upon this river used in getting up the formula were made upon the river in its natural bed, and the analogy between it and the small cement-lined channels of the Bazin experiments is too remote to permit any engineer to apply for practical purposes the formula to the case supposed. On the other hand, the Bazin formula, applied to this case, gives relative results not improbable. It being noted, however, that these opinions as to the result of this unjustified application of the Kutter rule have nothing of exactness, but are *impressions* and the result of speculations upon the subject. It is certainly true that whatever be the roughness of the bed, it produces resistances, not only by the adherence of the water, but by causing disturbances in the direction of the filets and their interpenetration, reducing velocity, and that these effects are less, in a general way, as the distance from their cause is greater, and are consequently less, as referred to the whole cross-sectional area of the stream, in large than in small rivers.

But it is not correct to say that the Kutter formula is wholly based upon the roughness of the bed. Darcy first called attention to the great influence of this roughness upon the velocity, which is a prominent feature in the Darcy-Bazin formula. He has also shown that the velocity is not proportional simply to the square root of the mean radius, but has also introduced this latter term into the expression for the *co-efficient*. In these two points Kutter has followed Bazin ; but he has gone further, and introduced the slope of the water surface.

The defect of the Darcy-Bazin formula is that it does not take into account the secondary effects of the slope in diminishing or increasing the co-efficients. The range of their observations being limited, and not including the large rivers of low slope of the Mississippi character, or the steep mountain torrents, these effects escaped their observation. It would be more correct to say they were not apparent within the limits of their experiments. In fact M. Bazin says (Ann. des., P. & C., 1875) that the first proposed form of his formula did contain, in the expression for the value of the co-efficient, the square root of the slope—

$$\left[A = \alpha + \frac{\beta}{R\sqrt{S}}\right]$$

which was afterwards omitted as not assisting the concordance of the results by formula with those of observation. It may be here observed that when the mean radius is one metre, the co-efficients are the same for all slopes, when less than one metre, they increase with the slope, when the mean radius exceeds one metre, the co-efficients diminish as the slope increases.

2d. On the proper exercise of the judgment of the engineer :

The point was made in this case, that it was immaterial what formula was used to compute the flow of water, because in every case corrections must be applied which required the exercise of judgment on the part of the engineer. It is not denied that the selection and application of any rule requires the exercise of an intelligent and instructed judgment. But it is as evidently true that every care must be taken to obtain the closest approximation and the least probable error, by careful selection of methods and comparison of the conditions with other known cases, the engineer exercising his judgment in this manner, rather than in making first a crude and probably erroneous calculation, and then guessing what modification should be made in the result.

It is thought that the application of the Chézy formula, with a co-efficient of 100, to the obstructed flood-channel at this place—observations upon no similar channel being on record—was not an exercise of good judgment. That, on the contrary, the selection of a point in Elmira which could be compared with other rivers as to its conditions, and the application to observations made at that point of methods which had given close results in the similar cases referred to, was the proper method of applying the judgment of the engineer to the case in point.

The use of any of the formulæ for the flow of water in open channels, which antedate those of Darcy and Bazin, is in the strongest terms to be condemned. Every day's experience confirms this fact. Made at first to represent the results of experiments, few in number, and of an unusual character, vitiated by the then admitted theory of the film of water lining the bed, and rendering the velocity independent of the character of the wetted surface, their co-efficients were framed to include in one unyielding formula the results of experiments, differing essentially in their conditions, and thus giving *averages* between widely differing limits. "The sweeping condemnation of all calculated mean velocity

"formula, with the exception of that of Herr Kutter, is * * *
"fully borne out by experiment" —the experiments of Capt. A. Cunningham, made upon the Ganges Canal.

Darcy has related the circumstances leading to some of the erroneous conclusions, which, once admitted, have been received with *almost* unquestioning faith.

The experiments of Couplet were made upon comparatively large iron pipes, 6" to 14", at Versailles, which prove to have been very rough with calcareous deposits. His experiments on small pipe, as well as those of Dubuat and Bossut, were made upon smooth tin pipes of one to two inches diameter. The roughness of the large pipe compensating for its greater diameter, the analysis of these observations seemed to justify the conclusion that the co-efficient in the mean velocity formula was independent, both of the diameter of the pipe, and of the condition of its interior surface.

Upon the Height of Backwater Produced by Contraction of the Water Way.

The most complete theoretical investigation of the subject is that of Dupuit, but experimental data are singularly rare. The observations upon the bridge of Minden, over the Weser, reported by Funk, and quoted in full by D'Aubuisson, have served for all the French and German writers to guide and test their theories.

The usual formula, that of Gauthey, in which he follows Dubuat, takes account in the first place of the head due to the difference of velocities in the large section above the bridge, and in the contracted section under it; that is v' being the velocity above the bridge, v'' the velocity under the bridge will be to the former in the inverse ratio of the areas of the water sections, the section under the bridge being reduced by a coefficient of contraction to take account of the retarding forces at the entrance between the piers. The velocity v' is due to the head $\frac{v'^2}{2g}$; the velocity v'' to the head $\frac{v''^2}{2g}$, the difference between the two is the height of backwater above the bridge. To this Gauthey adds the additional height due to the greater slope of the water surface in the length of the piers, but this quantity, generally very small, has been neglected by later writers.

According to Dupuit the principle upon which this rests is false. It may indeed be shown, that to change the velocity v', above the contraction to v'' in it, there must be a fall $h = \frac{v''^2 - v'^2}{2g}$, but it remains also to be shown how v'' becomes again below the contraction, v the original velocity. As the resistances in the contraction are not considered, this can only be by a rise $h' = \frac{v''^2 - v^2}{2g}$. But there can be no rise of the surface below the contraction, as it would give a height too great for the discharge. It must therefore be admitted that there is a fall in the contraction not produced by the raising of the surface *above*, but by the lowering of the surface *in* the contraction, to rise again to its original height. The additional rise above the original surface will therefore be that due to the retarding forces in the contraction, that is, between the piers of the bridge. These resistances are by the contraction increased above those of the natural bed, and *may be* equal to the depression $\frac{v'^2 - v''^2}{2g}$, in which case the latter will disappear, and the actual rise at the head of the piers will also be equal to the depression, and will be correctly represented by the Gauthey formula.

Dupuit supposes that the observations upon the Weser at the Minden Bridge took note only of the height of the back water above the depression at the lower end of the piers, and that the rise below this point was not noticed.

D'Aubuisson mentions in a general way the depression of water surface at the lower end of the piers.

Debauve (Manual del Ing'r. des Ponts et Chaussées. Hydraulique) follows generally the reasoning of Dupuit in the matter of contractions, substituting only the Darcy-Bazin formula for that of Prony for the movement of flowing water. For this particular case, however, he refers to his treatise on bridges, and in that work he adopts the formula of Gauthey.

If we follow Weisbach, who would apply the formula for discontinuous weirs, the height of the weir being zero, we are still without experimental co-efficients, upon which in every case, and especially in this extreme one, the accuracy of the result depends. This case more than the others calls attention to the propriety of making the co-efficients vary with the number of the piers, and with the width of the spans.

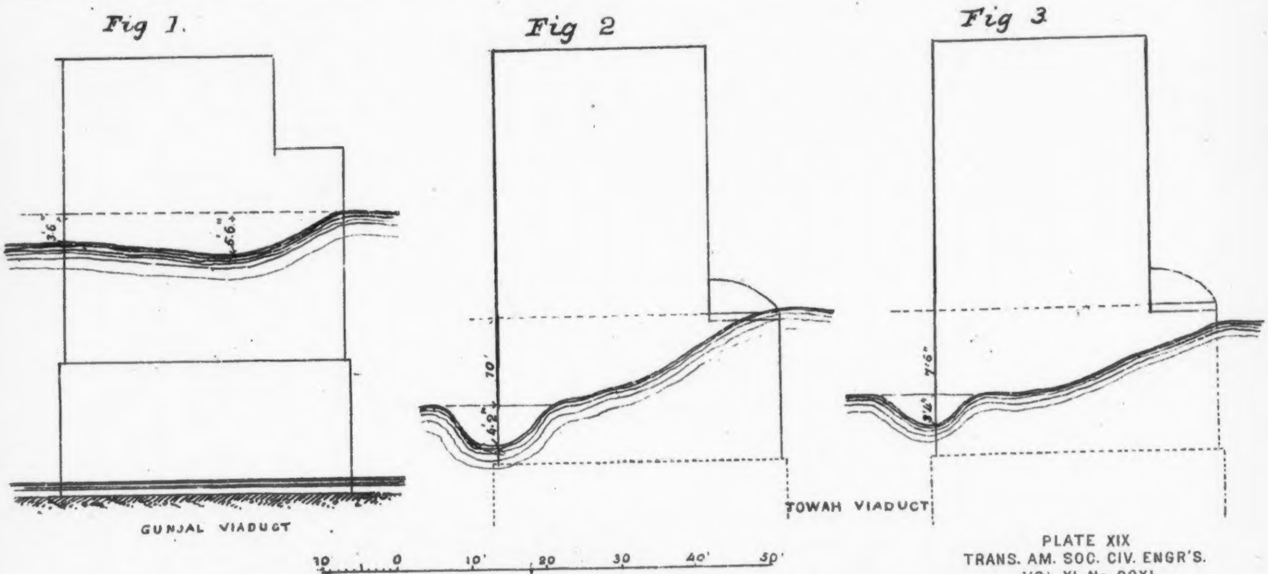

PLATE XIX
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HUTTON
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The dearth of experimental data is much to be regretted. Many engineers, railroad men, and especially government engineers in this country, and the corps of "Ponts et Chaussées," in Europe, who have charge of the entire river systems of France and Belgium, might without much labor, add largely to our stock of information on this point.

Dupuit admits that the resistances in the contraction are not capable of theoretical evaluation. The co-efficient of contraction recommended by Eytelwein, Gauthey, &c., &c., varies from 80 to 95, depending on the shape of the pier heads, and as they say, may well be larger for the larger bridges more recently built. But as Dupuit observes, the retarding forces depend on many causes besides the form of the pier heads. They depend on the relative velocities, on the thickness of the piers, on the size and shape of the openings, on the position of the bridge relatively to the shores, on the profile of the bottom, &c. It is at the lower end of the piers, just below the bridge, that the greatest loss of living force occurs. The water leaving with great velocity, produces there an agitation, and eddies, which are not observed above, which diminish the theoretical rise below and increase the height of backwater above.

Apart from theoretical considerations, we may with Dupuit consider some cases, to be convinced that the two quantities which are required to be known in the Gauthey formula are entirely insufficient. Suppose a channel 200 metres wide, to calculate the remous of a bridge of 120 metres span across it. For this case the formula gives (V being $2m$) height of remous about $0.36m$. But it is plain that the remous will vary with the disposition adopted. We may have a suspension bridge of $120m$, 12 spans of $10m$ or 5 of $24m$; the bridge may be placed in the main channel; the one abutment may be fair with, or project from the bank; the bridge may be at right angles, or oblique to the current. Any of these circumstances will affect the passage of the water through the openings, and therefore the height of the backwater.

In a paper on floods in the Nerbudda valley, by A. C. Howden, in Minutes of Proceedings of the Institution of Civil Engineers, Vol. XXVII, page 218, are given profiles of water surface during floods at the Gunjal and Towar viaducts (Figs. 1, 2, 3, Plate XIX), but the data are not sufficient to compare with any formula, or to obtain co-efficients. They both show the depressions below natural surface indicated by the theoretical investigation, which, however, are doubtless greatly reduced by the resistances in the waterway.

Dupuit's theoretical investigations of the movement of flowing water in an irregular channel include all the cases of contractions and enlargements. The retarding forces due to change of section although, doubtless, in some cases very considerable, are not taken into account, because we have no means of estimating them.

His conclusions may be thus summed up: if the contractions or enlargements are not of large extent, they produce at the point of greatest contraction a depression of the natural surface, and on the contrary a rise, in the case of an enlargement. But at the head of the contraction there is always an elevation of the natural surface, and at the head of the enlargement a depression. This elevation is the additional height necessary to overcome the additional retarding forces in the contraction, and the depression of the surface corresponds to the diminution of retarding forces in the length enlarged. These results follow whether the change of section be made by a lateral contraction or widening, or by a raising or lowering of the bottom. He treats in detail the case of a contraction by parallel dykes of limited length, and shows that if less than a certain length, given by his formula, they will cause a lowering of the surface, as it exceeds this length the surface will be raised until it reaches an elevation depending on the degree of contraction, and varying with the stage of the water.

His formulas indicate that the rupture of a dyke or the opening of a lateral outlet, by reducing velocity will cause an elevation of the water surface.

The Figs. 4 to 12, Plate XX, are taken from Dupuit's book. Fig. 4 gives the profile of water surface between bridge piers, the full line indicating the probable effect of retarding forces in the contraction. The dotted line, the theoretical profile, neglecting retardation due to change of section.

5 and 6 plan and profile of abrupt lateral contraction.

7 and 8 " " " gradual lateral enlargement.

9 profile of surface, due to elevation of bottom.

10 " " " " lowering of bottom.

11–12 plan and profile of gradual contraction of limited length.

The observations of Bazin are of interest as touching the general question, and show the general conformity of Dupuit's conclusions with his experiments.

Treating of the sudden rise of the surface (*ressaut*) which occurs when

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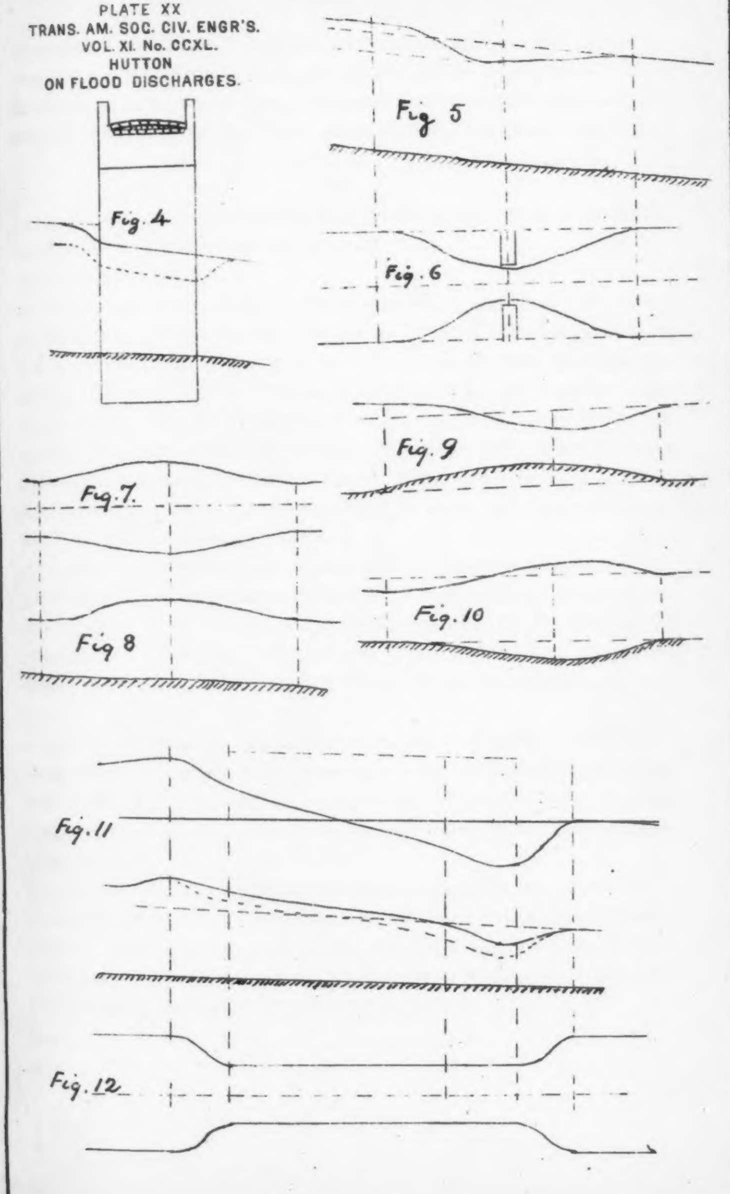

the velocity is suddenly diminished—the rise at the lower end of bridge piers is one form of this—the super-elevation of the backwater of a dam in certain cases is another form, he applies the formula of variable movement to the portion of the stream which includes this rise (*ressaut*).

$$H = a\frac{v^2 - v'^2}{2g} - \triangle.$$

$\triangle$ = loss of head due to friction of the sides, and eddies in the fluid,

h_1 and h = depth before and after the rise,

s = slope of bottom.

$H = h - h_1 - s$. The sides being smooth, $\triangle$ may be = 1.05.

Comparing the results with observation, he concludes that $\triangle$ is composed of two parts, one due to the friction of the bed, the other to eddies. When the rise is gentle, or the change of height not abrupt, the eddies are very slight ; $\triangle$ represents friction only, and is very small. H as calculated agrees very closely with H as observed. When the rise (*ressaut*) is sudden, the *friction* is slight (being on a very short length); that part of $\triangle$ due to change of section is great, and H as observed is less than H as given by calculation.

In the Aqueduct Bridge of Crau (Canal de Craponne), the rise (Fig. 13, Plate XXI), is caused by a sudden and considerable reduction of the rate of slope of the bottom. The calculated rise due to difference of velocities was 0.56*m* ; the height of rise observed was 0.45*m*; the loss of head therefore due to the sudden change of section (eddies, &c.) was 0.11*m*.

In the aqueduct of Marseilles, the *ressaut* (Fig. 14, Plate XXI), occurs at the lower end of the aqueduct bridge of Roquefavour, and is due chiefly to the sudden enlargement of section in passing from the masonry channel to the open canal, to a curve, and to a slight counter-slope below.

These extracts and references are given in the desire to excite interest in the subject, and to point out the kind of information and observations needed. There may be much already in print which has escaped notice in the preparation of this paper. If such shall be brought to light and made accessible, a good work will have been done.

Discussion by Theodore G. Ellis, Member A. S. C. E.

In the controversy between the Erie and Lackawanna Railroads to which Mr. Hutton refers, one of the points in question was regarding a proper formula to be used to obtain the discharge of the Chemung River, with the data given. These were, as stated by Mr. Hutton, the average slopes for four or five miles, the slopes for 2 400 and 2 800 feet, and cross-sections at three different places. With such data but the roughest approximation to the volume of discharge can be obtained. The refinement of using a somewhat complicated formula like Ganguillet and Kutter's in such a case is worse than useless. It gives an apparent accuracy where there is none in reality. In order to use any slope formula to obtain the discharge of a stream, it is necessary to know the slope with the greatest exactness, and to have the exact mean section of the bed through the whole distance. One section, or even several sections, will give no good approximation even, by which the discharge can be computed. It was in this view that some of the experts in the case referred to gave the opinion that the Chézy formula with a co-efficient of from 80 to 90 was a safer one to use, and just as likely to give a correct result as the Kutter formula. The question was not which is the best general formula, but what was the best suited to the peculiar circumstances of this case.

A very common error of the inexperienced is to imagine that by a multiplicity of figures and computations they can get exactness out of inexact data. In the present case, by any formula known, the result might be from one-half to three or four times the truth. It would depend entirely upon how near the slope and section were to the mean slope and section of the stream.

All formulas depending upon the slope and mean radius, whether they include the character of the bed or not, are indeterminate and misleading. It is not yet known even what roots of these quantities should enter into the formula. They vary in different authorities from the square root to the sixth root of these quantities, and it is not yet known whether the surface should be included in the perimeter or not, and more than this, there is no knowledge whatever as to the laws which govern the position of the thread of greatest velocity, and it is known that its relation to the mean velocity is not constant.

Kutter's formula is a good one, being an empirical formula derived

PLATE XXI
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Fig. 13.

Aqueduct of Crau.

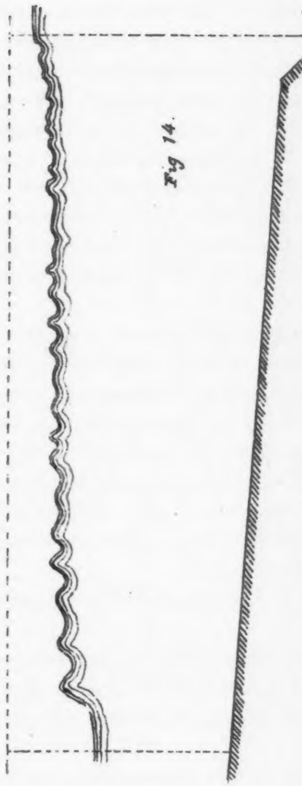


Fig 14.

Aqueduct of Marseilles.

from experiment, but only for the streams for which it was calculated. It is by no means certain to be correct for any other stream, though it is probably the best for canals and masonry channels that has yet been advanced. Its classification of the beds of channels is simply misleading. This was shown in the computation for the Mississippi to which Mr. Hutton has referred. He thinks the formula should not be used in that way. Why not? It gives a certain co-efficient to be used with certain roughness of surface in the bed. Now, if those co-efficients cannot be depended upon for all channels, what is the use of giving them. If the engineer has to vary this quantity for the size of the stream, why not exercise his judgment in the first place in fixing the value of the co-efficient in the Chézy formula from which Kutter's is derived. It would be much more simple and fully as accurate. The classification by absolute roughness in the Kutter formula is its chief point of weakness; if the roughness were made relative to the size of the stream, its deductions would probably be better.

In deriving their formula from the observations upon rivers, especially large rivers, a certain co-efficient of roughness was taken for their beds, and if this co-efficient is again assumed in a computation for their discharge, it would be very strange if the desired result should not be obtained. But if it is necessary to always use this co-efficient for rivers, no matter what may be their bed or its character, there seems to be no gain over the Chézy formula with a constant co-efficient. Mr. Hutton says: "The sweeping condemnation of all mean velocity formula, with the exception of that of Herr Kutter, is * * * fully borne out by experiment"—the experiments of Captain A. Cunningham on the Ganges Canal.

Let it be borne in mind that these experiments were very accurately made upon a large canal, being a regular channel, the exact character of whose bed was known, being the most favorable conditions possible for any such formula.

The maximum discrepancies between the exact gauging and the results given by the Kutter formula, are as follows:

In the right Solani aqueduct, from —21.7 to + 19.5 per cent.

In the embankment, main site, from —14.0 to + 42.3 per cent.

Thus, in a canal under the most favorable conditions, and with measurements taken with the greatest accuracy, being exact means and exact slopes, the Kutter formula is found to vary from — 21.7 to + 42.3

per cent. of the whole discharge. A total variation of 64 per cent. of the whole flow. So it seems that even under these favorable circumstances and in selected experiments, which prove the formula, it is barely possible the formula may be subject to a slight error.

Captain Cunningham says that the error of the Kutter formula will seldom exceed 7½ per cent. in large canals.

But for this accuracy it is essential that:

"The slope measurement should be done on both banks, always in calm air, and only when the canal is in train, and should be repeated several times."

"And further, for this accuracy it is essential that the 'rugosity coefficient' —*f*— be properly known for the site in the first instance. This of course can be only properly determined by experiment, *i. e.*, by determining a few experimental values of *C* from which to determine *f*, either by direct calculation, or by comparison with published tables. If the value of *f* be merely selected *a priori* by comparing the known state of the channel with the published classification, so close an approximation will be mere chance."

That is, in large canals, if you can compute the co-efficient from experiment, Kutter's formula will give the discharge within 7½ per cent. Cunningham also says: That the difficulties in this matter seem to the author "to make further research for an improved form of co-efficient almost hopeless from the experimental side, *i. e.*, until some help as to the proper functional form can be obtained from theory."

He also says:

"There can be little doubt that the mean velocity is in some way conditioned by the surface slope, but the law of connection is at present wholly unknown, the present formulæ being purely empirical, resting on no rational basis, and, therefore, only of limited and uncertain applicability."

It must be remembered that this is stated for regular canals where such formula are recognized as being most correct.

For rivers, it is the writer's experience that there is no positive relation between the volume of discharge and the surface slope. On the Connecticut River, where an exact survey of the bed of the river was made by sections every 400 feet, and in many cases only 100 feet apart, and the slopes were as carefully leveled as possible, a selection of the best experiments varied with the principal modern formulas from about

one-half to two and one-half times the measured discharge. In the opinion of the writer, the slope is so uncertain an element, that the co-efficient used in natural streams is within certain limits immaterial. The very best slope formulas can only be depended upon as an approximation to the real discharge. They should only be used where no velocity observations are attainable, one single velocity measurement in the middle of the channel being better than any or all of the slope formulas. It is only in such cases as the Chemung where the slope can only be taken from old marks that such a method should be resorted to, and then the channel in which the water flowed should be carefully measured and its mean section taken for the distance where the slope is known.

The complexities and refinements of such formulas as Kutter's, are only suited to regular channels like canals and sewers, where the slope is uniform and the resistances determinate.

For natural streams of small size also, where the slope is great, and the nature of the bed conforms to one of Kutter's classifications, the Kutter formula may be valuable, but for problems where the "guess and allow" and "average judgment" rules come into so great an extent as in the Erie matter, to try to get down to entire accuracy by any formula is absurd.

Mr. Hutton remarks that "the point was made in this case, and many times repeated, that it was immaterial what formula was used to compute the flow of water, because in every case corrections must be applied which required the exercise of judgment on the part of the engineer." Now, the writer was one of the experts employed by the Erie Railroad, and he certainly never made any such point or heard of its being advanced. The point he made was that with the entirely insufficient data given, there was no advantage in accuracy in using the Kutter formula over the Chézy formula with a proper co-efficient. The idea that it was immaterial what formula was used is simply absurd. Very few of the older formulas are even approximate under the best of conditions, and Mr. Hutton's remarks about them are entirely correct. The Chézy formula, however, still holds its own against most of its competitors, and for all practical purposes is as accurate for natural streams as the more complicated one of Kutter derived from it. With exact data and careful measurements of slope and bed, the Kutter formula is admitted to be the most likely to give close results, but when uncertainties are introduced it is best to adhere to the more simple form. The uni-

formity of co-efficients given to the Chézy formula by different authorities is a high recommendation of its general use. Eytelwein gives 93.4, Young 84.3, D'Abuisson 95.6, Downings & Taylor 100, Leslie 68 and 100, Stevenson 69 and 96, Beardmore 94.2, and Neville 92.3, and 93.3.

The mean of these is about 90, which is perhaps the best general coefficient. For the Chemung, with its overflowed banks and obstacles in the bed, 80 was recommended, and it would be almost a miracle if the result of this or any other formula with the data given would give accurate results.

Mr. Francis' estimate of the discharge, being a mean between the two quantities of 55 860 C. F. per sec., and 169 444 C. F. per sec., is 112652. These amounts are wider apart than any of the coefficients of the Chézy formula, and it is not exactly seen how they prove the accuracy of the Kutter formula by having their mean agree with its results.

DISCUSSION BY ROBERT E. MCMATH, MEMBER A. S. C. E.

Since the Roorkee experiments of Capt. Cunningham make no exception in favor of Herr Kutter's formula when making a sweeping condemnation of all calculated mean velocity formulæ, there is manifest need of a practical method of meeting the question presented in Mr. Hutton's paper.

In important cases, like the one stated, I propose the following as practicable, and giving a close approximation to results obtained by direct measurement.

The problem is to determine the discharge of a river at a given date of which the sole record is the stage.

Where, as seems to have been the case with the Chemung, a reach can be found in which the river is confined to a definite bed the matter is simple, but requires time and labor. Assuming that a section can be found affording a considerable area at the lowest stage, it is necessary to determine by observation the mean velocity of flow at stages differing as much as possible. A short series at a low and another at a high stage will suffice, but others at intermediate stages are desirable to establish the result.

These mean velocities will, under the condition of a large low stage area, when plotted as abscissas to stage of water as ordinates, lie on or

very near a straight line. Extending this straight line from the highest stage of measured discharge to the height of the recorded or traditional flood, the abscissa of the line at that height is the mean velocity which would result if the stream should now rise to the recorded level. Having the area the discharge is known. Such discharge may be attributed to the former date with liability to error, only as the local area has changed and as the crest of the bar or dam next below the observation site has been raised or lowered. In rivers of permanent character the changes by natural causes will be small; obviously the change of local area would equally affect any computation. Variation of the bar or weir height is a change in the level of no discharge, or the origin of velocity.

Should no locality be found where the stream was within banks at flood, another important condition must be observed. The stream at the selected site must conform to the general direction of the valley; that is, the direction of flow within and without the banks must be sensibly the same. The method proposed will give the mean velocity within the limits of the principal banks. The volume flowing over the bottoms must be estimated as best it may. I would only say that all computations tend to exaggeration of the overflow water.

In a series of observed discharges of the Mississippi, below Memphis, 16 out of 66 were used to determine the line of mean velocity according to the proposed method. By the resulting equation $V' = 0.0725$ (gauge reading $+ 37'.2$), a series of V' was computed which when compared with the V by direct measurement gave: sum of 66 residuals $[V' - V] = 5'.481$, whence mean error $= 0'.083$: minus errors 31, sum $2'.438$, mean $0'.078$. Plus errors 35, sum $3'.053$, mean $0'.087$. The maximum error was $0'.366$ in a velocity of $4'.873$, or $7\frac{1}{2}$ per cent. The per cent. of error between computed and observed velocities was in

22	cases	less than	1	per cent.
38	"	"	2	"
47	"	"	3	"
57	"	"	4	"
63	"	"	5	"
65	"	"	6	"
66	"	"	8	"
The mean error being			$2\frac{1}{6}$	"

The range of stage covered by the observations was from $6'.0$ to $27'.0$. The greatest observed discharge was 825 000 cubic feet per second. Ex-

tending the computed V' to a 29 foot stage, the maximum discharge for the year 1879 is found to have been 911 400 cubic feet between banks. During the recent high water, March 6-9, 1882, the data indicate a discharge between banks of 1 251 200 cubic feet per sec., stage 37'.9.

Assuming that the volume, including overflow water, at top of flood of 1882, was 1 700 000 (a fair approximation), the height to which the flood would have risen if confined within width of 4 700 feet would have been $37'.9 + 9'.9 = 47'.8$ for $A\,v = 1\,251\,200$ = determined Q at stage 37.9, and $A'v' = 1\,700\,000$ = Assumed Q' at stage $37.9 + h'$; $A = 230\,000 \square'$; $v = 5'.44$; $w = 4\,700'$; $h = 37'.9 + 37'.2 = 75'.1$; then $(A + w\,h')\,(h + h')\,0.0725 = 1\,700\,000$; whence $h' = 9'.86$.

I have now for illustration applied the method to two problems, neither of which could have been satisfactorily solved by the methods heretofore in use. I have also shown the degree of approximation reached by the method in an unstable river. The section enlarged by scour, 10 400 square feet, and then returned to its first condition during the observations. This change affects the velocity somewhat but the residuals were mostly the effect of variation in the level of no discharge, by scour and fill at the bar next below the observation site. In a stable stream the approximation ought to be closer. The observations which were made by H. B. Herr, C. E., assistant under Major W. H. H. Benyaurd were exceedingly well made, and the site happily chosen.

Discussion by William R. Hutton, Member A. S. C. E.

As Major Cunningham concludes that "Kutter's co-efficient c is of pretty general applicability," and that with accurate data it will give reasonably correct results, he, at least, does exclude the Kutter formula from any "sweeping condemnation" of calculated mean velocity formulas. He would, indeed, prefer a formula depending upon velocity measurements rather than on measurements of slope, but he does attempt to construct one.

It is to be hoped that further observations may confirm the correctness of the very simple method proposed by Mr. McMath, which will be an invaluable practical advance if it should prove of general application.

It was not the author's intention in the original paper to assert that the Kutter formula was under all circumstances reliable and accurate in its results. It is a great improvement upon all other general formulas, and the best we now have.

General Ellis was connected with the Elmira case only towards its close, and seems not to have understood that no attempt was made on the part of the Lackawanna Company to obtain the correct discharge of the Chemung River by the application of the Kutter formula to the data mentioned by him, which were obtained at the site of the crossing. The general facts connected with the construction of the formula, were, indeed, introduced to show that the co-efficients applied to these data by the Erie experts, were by far too large, but the results presented were obtained at a different site, where the conditions were much more favorable to an accurate gauging.

It is true, the Lackawanna expert did contend that as the discharge of a stream is dependent upon several conditions and several relations of these conditions, reliable results can only be obtained by introducing the conditions and relations into the formula. If some complications result, the blame must be laid upon the stream which refuses to be governed by more simple laws. The complications too, are greatly exaggerated. The Chézy form is adopted as being the most simple. The "complications" are confined to the formula for the co-efficient, and may be avoided by the use of tables or the diagram. In addition to the operations required by the Chézy formula, eight others are required to obtain the co-efficient, and of the simplest character, such as can readily be computed in five to ten minutes.

It is also true that much remains to be learned of the laws which affect the movement of running water. The empirical formula, however, now under discussion, makes no reference to those laws, but is based upon observations solely. The question is only as to its correct representation of those observations, and its applicability to similar cases.

Neither is it correct to say that all formulas depending upon the slope and mean radius are indeterminate and misleading. The cases in which they are not applicable are rare. And although some authorities do assert that the velocities vary with the sixth root of the slope, some with the fourth root, and others, by far the greater number, with the square root, the Kutter formula, containing the slope in the equation for the co-efficient, indicates that the relation between velocity and slope is a complex one, not to be represented by any single exponent. In rivers of small slope, and particularly in large rivers of that character, the exact determination of the slope is not easy, and results obtained from slope formulas are therefore more liable to give in-

correct results, more especially as its relation to mean velocity in such cases is not so well determined. The position of the thread of greatest velocity does not appear in any of these formulas, and it may be higher or lower in the same vertical, without sensibly affecting the mean velocity of the section.

It is asked why the Kutter formula for cement lined channels should not be applied to the Missisippi, supposing its bed plastered with cement. The reason is obvious. An empirical formula, based upon observations, cannot safely be applied to cases exceeding greatly the range of the experiments from which it was derived. The co-efficients of roughness for rivers in earthen beds, were derived from observations upon rivers both large and small, and they may be applied to all. Those upon cement lined channels were from experiments upon small channels only, none exceeding two metres wide, and their application to the Mississippi is an extension too far beyond the cases which served for their formation.

The co-efficient of rugosity is criticized as being independent of the size of the stream, but this is not the case. Certainly n is invariable for each class or category, but being divided by $\sqrt{R}$ in the formula for the co-efficient, it practically varies inversely as the square root of the mean radius, which represents the size of the stream.

Kutter remarks that the Darcy-Bazin observations prove that the degree of roughness of the wet perimeter has a very important influence on the value of the co-efficient in small sections; the proportions of their formula show that it decreases with increase of sectional area, and, although it never entirely vanishes, is inconsiderable in very large rivers like the Mississippi.

Gen. Ellis correctly states the maximum discrepancy between the exact gauging made by Major Cunningham, and the results calculated by the Kutter formula to have been, at one site, from + 19.5 per cent. to —21 per cent., and at the other side + 42.3 to—14 per cent. Yet of 83 observations and comparisons, including these exreme ones, the mean discrepancy was about 5 per cent.; 70 observations differed not more than 7½ per cent., and 50 agreed with the results of computation within three per cent. Moreover Major Cunningham remarks that many of the observations which differed more than 10 per cent. from calculated discharges were not nearly so well determined as the others.

The conditions quoted from Major Cunningham go to show, as might be expected, that the accuracy of the computed results will depend on

the accuracy of the data. He refers to large canals because his experiments were made upon canals of that class, and he limits his remarks to the cases within his observation. The comparison of the results by this formula with gaugings of numerous rivers of Europe, as given in Kutter's papers, show that its applicability is not limited to large canals. He correctly says that the Kutter formula is purely empirical, and only of limited and uncertain applicability—"limited" to the range of cases from which it was constructed, and "uncertain" whenever those conditions are departed from.

General Ellis' very careful and valuable experiments upon the discharge of Connecticut rivers, have been discussed by him as to the mean velocity on each vertical, its relation to mid-depth velocity, and the use of observed velocities to determine the mean velocity of the stream, but he has not published any comparison of his results with those given by any formula applied to the same conditions.

Time has not permitted an analysis of these experiments with a view to the comparison of them with formulæ containing the slope. A partial investigation discloses very great discrepancies, and indicates a possible reason for them. Tested by Captain Cunningham's conditions, the site was not a favorable one for this purpose however suitable for the object for which it was adopted.* It is situated in marked hollows in the bed slope. The water is from 8 to 18 feet deep when its surface is *about* level with the crest of Enfield dam which is 4 800 feet below the lowest section station, and one of the sections has a *mean* low water depth of but 3.2 feet. Applying the Chézy formula to some of the observations, the co-efficients are found to vary between the same stations from 132 to 62, varying with the height of the water, and diminishing rapidly as the height approaches low water. The discharges appear to vary nearly as the square root of the cube of the height above a certain point which is about 1.5′ lower than lowest water recorded. Many of the slopes are very small, a number of them are less than 0.1 feet in a distance of 6 200 feet, and they appear to vary, possibly with the wind, without corresponding influence upon the discharge. The case seems to be analogous to the two experiments of Dubuat upon the river Hayne, rejected by Humphreys & Abbot, because a lock inter-

* Capt. Cunningham (Roorkee Expts., 1881), considers one of his Belra sites to be unfavorable, because the bottom is 2 feet lower than the sill of a bridge 1 800′ above, and as much below the level of a dam 4 miles below it.

rupted its flow and reduced it to a kind of elongated basin, with an almost inappreciable slope. The relation of discharge to height of water surface resembles the law of discharge over a weir, and suggests their dependence upon the level of the dam or the bar below them. It will be observed that small as are the slopes, their effect is much less than would be indicated by Kutter's or any other slope formula, unless indeed the bed is very rough, which it is understood, was not the case.

Mr. McMath has shown that these observations conform very nearly to his newly published law, that in certain (numerous) cases that velocity varies directly as the stage.

The same results have been observed before in a similar case—that is, the Chézy co-efficient of velocity, has been found to diminish very rapidly and become very low, about the same as here, viz.: 62, when the stage approached lowest water. This upon a pool 10 miles long, 5 to 12 feet deep at low water, closed at its lower end by a bar, having a narrow, shallow channel.

The object of the writer in the Elmira case was to get rid of the "guess and allow," and "average judgment" rule, and where positive data were not obtainable, methods were adopted, which would give maximum results, such as could not be criticized by the opposing counsel as too small.

But it cannot be admitted that where uncertainties are introduced in the data, it is best to adhere to the more simple form. If the data are good enough to warrant their use to determine the discharge, then the best results—results which will approach the truth in proportion to the accuracy of the data, will be obtained by their application to the actual conditions of the case. The older authorities, those preceding Darcy and Kutter use different co-efficients in the Chézy formula, some preferring one, some another, and a few using two for different cases, varying from 68 to 100. Kutter uses the whole range between and beyond these figures, and defines the conditions which require their use.

The references to Mr. Francis' results quoted by General Ellis are from the report of the Commissioners, and have no reference to the Kutter formula.

Van Nostrand's Magazine for June, 1882, contains a full discussion of some of the questions here treated, in a paper on the "Obstruction to River Discharge by Bridge Piers, by General Q. A. Gillmore, U. S. Engineers," and is based upon the circumstances of the Elmira crossing case.

This paper has been reviewed in "Engineering News" of 17th June last, and the references by the reviewer to the present paper and its author, seem to justify a notice of them in this discussion.

It is not proposed, however, to open any new points, or to repeat what has already been said. The interesting discussions upon the velocities of the stream and their power to move large stones, do not call for any notice, as it has been shown that the velocities could not be correctly obtained from observations made at the site, similar to those relied upon in the paper referred to.

To determine the increased rise which would be caused by the contraction of the water way by the works of the Lackawanna Company, two formulas are used, which furnish very different results. The first is that of Eytelwein, the second is quoted from Debauve (*Manual de l' Ingènieur des Ponts et Chaussées. Ponts et Maçonnerie*), but had long before been given by D'Aubuisson. The great discrepancy in the results given by these two formulas (the rise y by the Eytelwein formula would be 2.3′, by that of D'Aubuisson 4.3′), both of them founded upon the same general principle, has suggested an examination of the process by which they were constructed, which seems to be worth recording.

Dubuat, with whom the method originated, assumes that there will be no considerable change of velocity in the section above the contraction. Consequently the velocity in the contraction will be to that above it, inversely as the sections, $v_{,,} = \frac{v_{\circ}\, W}{w}$, and the difference of the heights to which these velocities are due will be $y = \frac{v_{,,}^2 - v_{\circ}^2}{2g} = \frac{v_{\circ}^2 W^2}{2g\, w^2} - \frac{v_{\circ}^2}{2g} = \frac{v_{\circ}^2}{2g} \left(\frac{W^2}{w^2} - 1 \right)$; and the co-efficient which is to compensate for the contraction of the stream in the narrow water-way is applied to the resulting height, so that in its final form we have $y = \frac{v_{\circ}^2}{m^2\, 2g} \left(\frac{W^2}{w^2} - 1 \right)$.

In the first edition (1801) of his *Handbuch der Mechanik und der Hydraulik*, Eytelwein follows Dubuat in neglecting the diminution of the velocity above the contraction, caused by the raising of the surface, but he applies the correction for contraction to the narrow section only. Thus making $y = \frac{1}{m^2} \left(\frac{v_{\circ}\, W}{w} \right)^2 - \frac{v_{\circ}^2}{2g}$ or $\frac{v_{\circ}^2}{m^2} \left(\frac{W^2}{w^2} - \frac{1}{2g} \right)$; m being in this case $\sqrt{2g} \times 0.95$.

In the edition of 1843 of the same work he makes $v_{,,}=\dfrac{v_{\circ}\,Q}{(w\,(h+y)}$ $=\dfrac{v_{\circ}\,Wh}{w\,(h+y)}$ and $y=\dfrac{v_{\circ}^2}{m^2}\left(\dfrac{Wh}{w\,(h+y)}\right)^2-\dfrac{v_{\circ}^2}{m^2}$ or $\dfrac{v_{\circ}^2}{m^2}\left(\dfrac{W^2\,h^2}{w^2\,(h+y)^2}-1\right)$, as quoted by General Gilmore.

It will be observed that $v_{\circ}$ being original mean velocity, $v_{,,}$ (that between the piers) is not $\dfrac{Q}{w\,(h+y)}$ but simply $\dfrac{Q}{wh}=\dfrac{v_{\circ}\,Wh}{wh}=\dfrac{v_{\circ}\,W}{w}$. Again, as the second member of the primary equation is the head due to the velocity above the contraction, it is equal to $v^2\left(\dfrac{W\,h}{W\,(h+y)}\right)^2=$ $v_{\circ}\dfrac{h^2}{(h+y)^2}$ which does not vary with the co-efficient of contraction. Substituting we have $y=\dfrac{v_{\circ}^2}{2g}\left(\dfrac{W^2}{m^2\,w^2}-\dfrac{h^2}{(h+y)^2}\right)$, m being the usual co-efficient of contraction applicable to the character of the entrance to the contraction. This form involves smaller numbers than the formula quoted by General Gilmore from Debauve, but it is substantially the same.

The discharge of the main river is computed by Darcy's formula, by that of Humphreys & Abbot, and by Kutter's, making in the last the co-efficient of rugosity, $n=0.026$ "for large rivers." This is thought to be unwarranted by the circumstances. n does not depend on the size of the stream, but on the condition of the bed. Making $n=0.035$ as for "rivers and canals in bad order and regimen, overgrown with vegetation, and strewn with stones, or detritus of any sort," or "with beds and banks in bad order having irregularities and deposits of "stone and much overgrown with vegetation"—with this value of n we have the volume of discharge 133 900 cubic feet—and the table given, when extended to include this value, and omitting the results of the Eytelwein formula for rise, will be as follows :

Formula for Velocity.	Volume of Discharge Cubic feet.	Formula for Rise. Debauve (D'Aubuisson).
Downing	202.059	4.3168′
Bazin	197.693	4.1113′
Humphreys—Abbot	131.573	1.7587′
Ganguillet & Kutter, $n=0.026$	161.010	2.6775′
do. do. $n=0.035$	133.900	1.826′

The map accompanying the paper is deemed to offer ample evidence of irregularities and vegetation, while the description of page 444 indicates detritus and deposts of stone.

It will be remembered, also, that on the trial the Lackawanna Company claimed that these irregularities were such as could not be compared with any other stream which had been gauged under similar conditions, and that a reliable computation must be based upon observations at a place comparable with some experimental site.

The reviewer in "Engineering News," referring to the Elmira case, says that the Lackawanna expert selected "the bridge crossings at Elmira, "of which there are three of varying lengths, and a mill dam, in the dis- "tance, on the river of little over half a mile. * * * Whether "he used one bridge or all three, or the slope resulting from the "combined obstacles of the locality, or finally what was the degree of "roughness allowed for in the Kutter formula," * * he does not know. As the points mentioned were given in the evidence they could easily have been ascertained. It is hardly necessary to say that these insinuations are uncalled for. The observations were made in an unobstructed, straight portion of the channel, and the co-efficient of roughness selected after careful examination of the site and comparison with other rivers, was that of Kutter's second class of earth channels, such as are in moderately good order in every respect, 0.030. The distance between sections was less than would have been preferred, but the data were by far the most reliable to be obtained.

The review contains extracts from an article in "Engineering" (quoted from Van Nostrand's Magazine of 1873, p. 320), which is said to show that the invariable co-efficients of the older authors are incorrect, and that C should vary with the discharge of the stream. Those interested are referred to a more recent editorial in the same able paper on p. 517, of vol. XX, 1875, which is too long to be quoted here.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CCXLI.
Vol. XI.—July, 1882.

ACCURACY OF MEASUREMENT AS INCREASED BY REPETITION.

BY STEPHEN S. HAIGHT, Member of the Society.

PRESENTED AT THE ANNUAL CONVENTION, MAY 17TH, 1882.

Probably most of the instruments in use for the measurement of angles are so graduated that the smallest reading that can be made with them is one minute.

Although this is a great advance upon the old compass, divided into quarter degrees, it still permits errors much too large for careful surveying, if means are not provided for securing greater accuracy.

This provision is made by repeating the measurements.

In the work of surveying and monumenting the new streets of New York City, the limit of error is five seconds per angle and fifteen one-hundredths of a foot for each one thousand feet of measured traverse, as found by calculation; yet there is little difficulty in keeping within this limit with a twenty-second transit and a chain adjustable for temperature.

The repetition of the linear measurements is simply for each chain length, until the forward chainman becomes satisfied that the centre of his pin, where it enters the ground, is precisely beneath the point of his plumb bob, the pin being so placed as to be at right angles to the line and in as near a horizontal position as it can be made firm.

The short measurements with a steel pocket tape are made level by means of running one end up and down a plumb line and repeating the process until the shortest distance between two fixed points is obtained.

Horizontal measurements with the chain are secured by means of a level bubble attached to one end of the chain and forming a part thereof.

Six repetitions are usually made of the angular measurements, but not by computing the mean of six independent readings.

With the vernier at zero, the vertical hair of the telescope is carefully placed so as to cover the left hand point, with the instrument clamped ; then loosening the vernier, the glass is turned toward the right and is fastened so that the second point is covered by the hair.

The reading being noted, the instrument is unclamped and turned to the left and made fast so that the vertical hair again covers the starting point. Upon loosening the vernier and turning the glass so as to again cover the second point, the second measurement has been made from the end of the first, instead of afresh from zero, and if the vernier is read it will be found to be approximately twice that first noted.

It is not advisable, however, to read the limb after noting the first measurement until the close of the sixth, when the reading, being added to the number of complete circles that may have been turned, and the sum divided by six, the quotient may be accepted as the size of the angle.

This, in good work, will always be within twenty seconds of the first reading if a twenty second instrument is used, or within one minute if the instrument reads only to minutes.

The measurement so obtained is incomparably more reliable than the average that is deduced by dividing the aggregate of six separate readings by six.

The principle of this method may be illustrated by linear measurement, as shown on the diagram, page 250.

It is desired to measure the distance between two points that are three centimetres apart, giving the distance in ten-thousandths of a foot,

the smallest subdivision of the scale being one one-hundredth of a foot in length.

As three centimetres are equal to a very little more than nine hundred and eighty-four ten-thousandths of a foot, the first reading will be a little less than one-tenth of a foot, and the measurement cannot be made more nearly by any number of independent readings.

The desired result can be easily effected by taking the distance between the points of a pair of dividers and carefully stepping six times along the scale from zero. The end of the sixth step will be a little beyond fifty-nine one-hundredths of a foot; the quotient obtained by dividing this by six is nine hundred and eighty-three and one-third ten-thousandths of a foot, which differs less than one ten-thousandth of a foot from the actual length of three centimetres.

Owing to unavoidable errors in all instrumental work, it is rarely the case that the angular closing of a polygon will be precisely in accordance with theory.

The probable error in the measurement of each angle can be calculated by apportioning the aggregate error of the polygon among all the angles, with a closer approximation to the truth than by the use of any set formula.

In making this apportionment it should be remembered that the shorter the radius the greater the liability to angular error, and it would seem to be most in accordance with good judgment to make the greatest correction in that angle whose sides are the shortest.

The calculation of the co-ordinates of the several stations of the polygon, or of their latitudes and departures, will sometimes show that a proper balancing of a survey will require that the whole aggregate angular error of the polygon should be corrected in some few of the angles while others are taken as measured.

A simple method of testing the accuracy of angular measurements is by adding together all of the interior angles of the polygon (the supplements being used of those measured exteriorly).

Whatever the aggregate may differ from an exact multiple of ninety degrees will, of course, be the error of the polygon, and the quotient arising from dividing this error by the number of angles measured will be the error per angle, which may be corrected as previously stated, if less than five seconds.

In dividing a large block into smaller ones by cross lines it is often

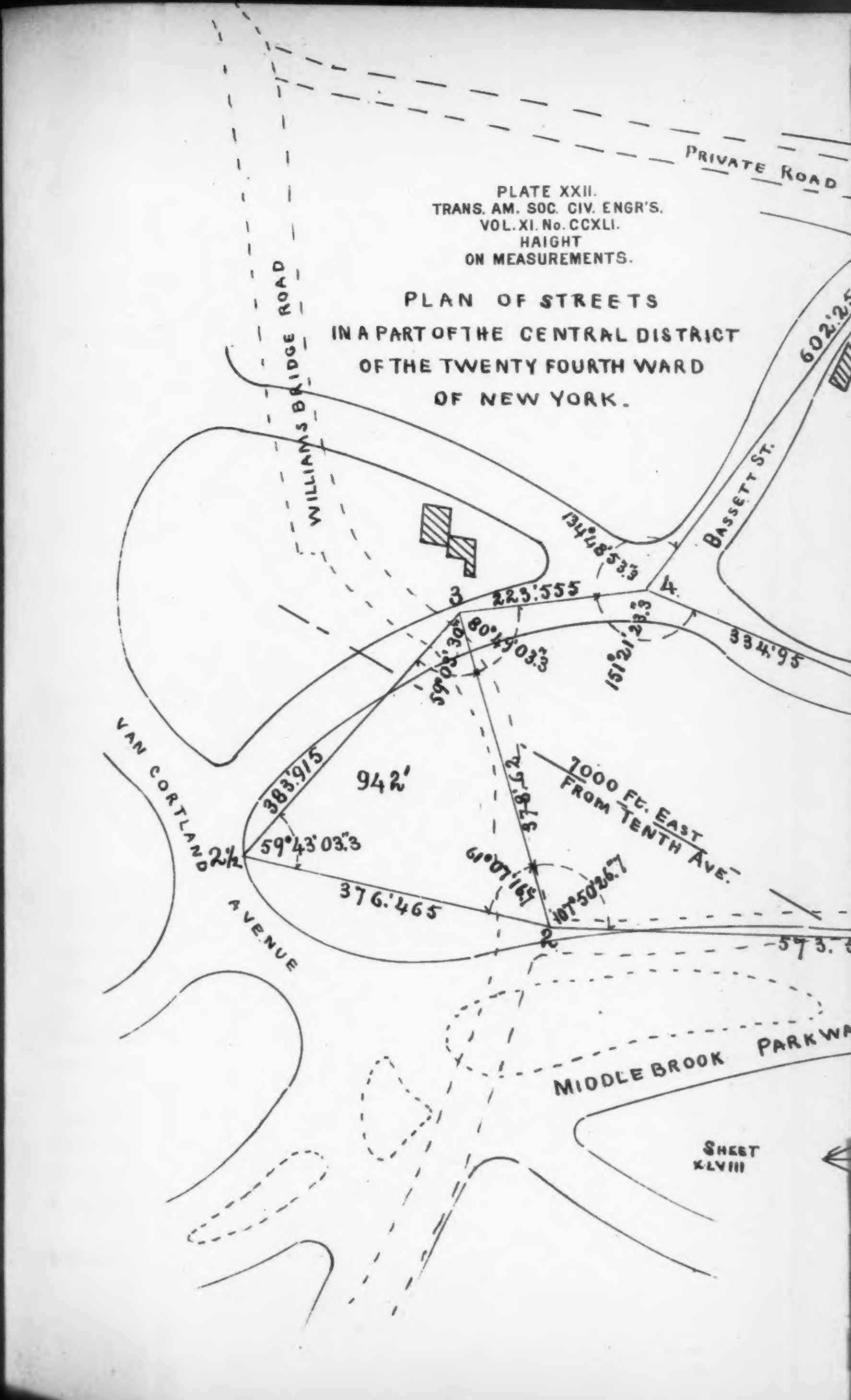
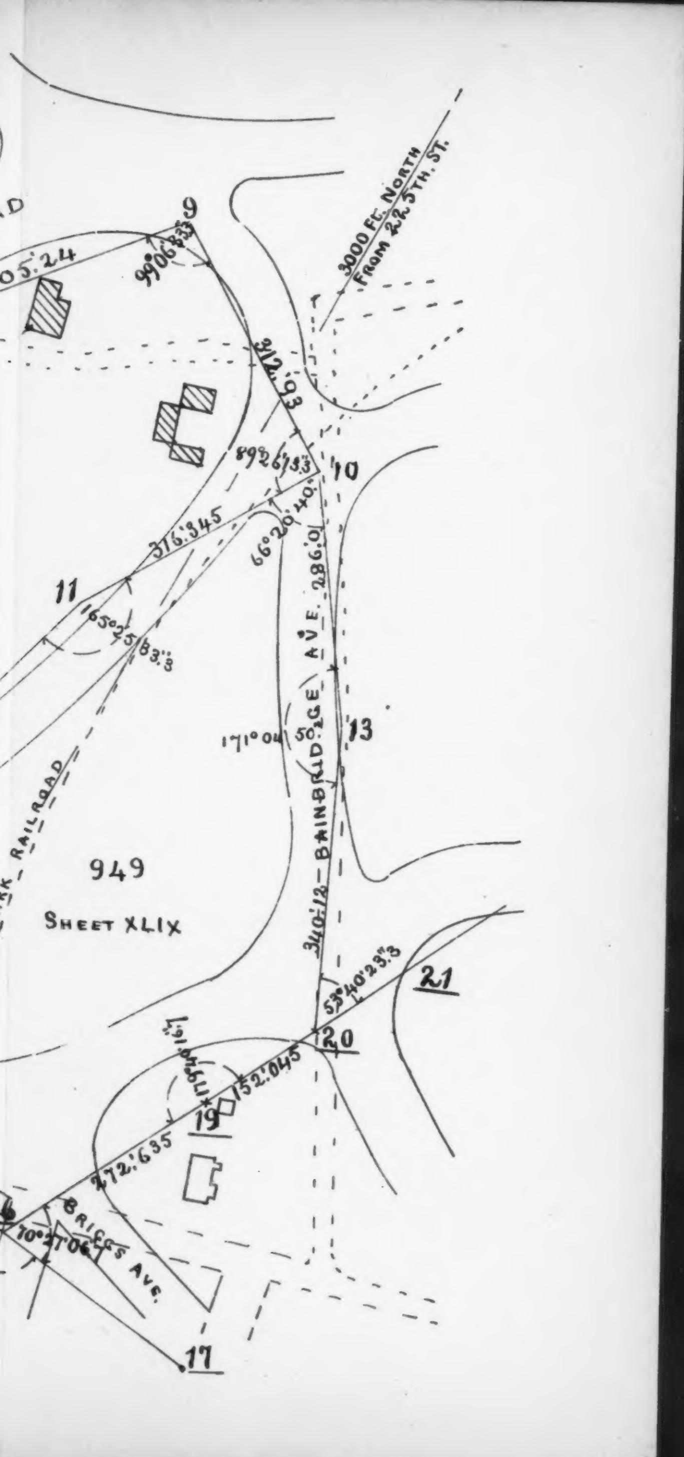


PLATE XXII.
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XI. No. CCXLI.
HAIGHT
ON MEASUREMENTS.
PLAN OF STREETS
IN A PART OF THE CENTRAL DISTRICT
OF THE TWENTY FOURTH WARD
OF NEW YORK.
PRIVATE ROAD
WILLIAMS BRIDGE ROAD
BASSETT ST.
602.25
134°48'53.3
3
223.555
4.
80°49'03.3
59°03'30.4
151°21'23.3
334.95
VAN CORTLAND
AVENUE
383.915
942'
378.62
7000 Ft. East
From Tenth Ave.
2½
59°43'03.3
61°07'16.5
107°50'26.7
376.465
2
593.5
MIDDLE BROOK PARKWAY
SHEET
XLVIII

ROAD
6
98°01'36"
410.435
WOODLAWN ROAD
602.25
129°11'53.3"
405.24
116°54'46.7"
7
139.58
124°55'10"
8
941
11
482.09
126°09'43.3"
5
NILES ST.
497.62
BUSSING ST.
942
152°24'03.3"
JEROME PARK RAILROAD
181.43
12
1
SHE
54°38'20"
143°42'23.3"
S. 9° 04'43" W
393.636
RKWAY
PL.
2950.217 N.
7037.461 E.
TRUE MERIDIAN
28°50'30"
44°29'00.7"
15
14
163.32
16
POTTER
152°37'53.3"
163°41'
70°27'00"


9
10
11
13
17
19
20
21
3000 FT. NORTH
FROM 225TH. ST.
BAINBRIDGE AVE.
RAILROAD
BRIGGS AVE.
949
SHEET XLIX
316.345
286.0
340.12
152.045
272.635
165°25'83.3"
171°04'50.2"
66°20'40"
89°26'13.3"
99°06'33"
53°40'23.3"

found that the aggregate angular errors of one of the subdivisions is plus, while those of the adjoining block are minus, so that a judicious correction in balancing will improve both.

Sometimes there will be little error in the angles of a large polygon, while the excess in one of its subdivisions and the deficiency in another will be each greater than the allowable error.

Where this is the case the angles of the cross line should be remeasured.

On the accompanying map, (Plates XXII, XXIII,) which is a plan of streets in a part of the Central District of the Twenty-fourth Ward of New York City, the traverse lines are shown, dividing a block into four smaller ones, with the size of angles and lengths of lines as actually measured.

The readings of each angle are given (and the mode of testing as described for each block) on separate sheets, pages 249 and 250, and Plates XXIV, XXV.

A table is also given of the calculation of co-ordinates of the traverse stations ; station fifteen being used as the initial point and the line from station fifteen to station one being assumed as north.

All but four of the stations of this survey are on rock or large boulders, the station being at the intersection of two fine lines cut with a chisel in the form of a rectangular cross.

The lines connecting stations, the numbers of which are underlined, form portions of blocks that were surveyed in October, 1881, and were connected with the other stations, as shown on the map, in February, 1882.

Such accurate work will, of course, require more time for its performance than surveys of a rougher kind, and it may be of interest to state that the writer with two chainmen was engaged seven days in February, 1882, upon the surveys here shown. The establishment of points and clearing of lines took considerable of this time, and the ground being covered by deep snow made the progress slower than it would otherwise have been. Under more favorable circumstances the same party has frequently measured more than half a mile in a day, so that the survey would close with less errors than would have been allowed.

Occasions constantly arise where it is necessary to establish points at a prescribed distance and angle from some other point and line.

The repetition of the measurement of the angle is here of great service.

The desired angle being approximately turned, a stake is firmly driven on the line, at some point where its top will be visible from the transit, and (if practicable) at a distance found by pacing to be somewhat in excess of that prescribed.

A pin or match being firmly placed in a vertical position on the top of the stake, on the line as given from the transit, the angle is carefully measured with six repetitions, as previously described.

The difference between the prescribed angle and one-sixth of this last reading will be error, which may be corrected by moving the pin or match to the left or right, according as the error may be plus or minus, a distance equal to the product of the sine of the error multiplied by the distance of the stake from the transit.

The sine of sixty seconds being approximately thirty-one hundred thousandths, a simple and easily applied mode of correcting the error is to multiply half the number of seconds in the error, regarded as hundredths of a foot, by the number of feet that the stake is distant from the transit, expressed as thousandths. The product is the distance that the pin must be moved at right angles to the line to place it on the prescribed line.

When the distance is short a less number of readings than six may be taken.

As the error will seldom be as large as the smallest reading that can be made with the instrument, and the line rarely more than two hundred feet in length, this mode is practically accurate, even with the correction based upon the distance being obtained by pacing.

This proposition may be demonstrated as follows, viz.:

Twenty seconds error would appear by this rule to cause a departure of ten one-hundredths of a foot in one thousand feet; or two one-hundredths of a foot in two hundred feet.

This differs less than seven ten-thousandths of a foot from the correction that would be obtained by using the sine to the seventh decimal place.

With an error of twenty seconds in the angle a difference of ten feet, more or less, in the distance would make a difference in the departure (or distance to move the pin) of only one one-thousandth of a foot; therefore when the distance is short it can be obtained by pacing with sufficient accuracy for correcting the angle.

It is safer, however, to roughly measure the distance that may be in

excess of that which was prescribed, which last will, of course, be measured with care; and if the angular error exceeds twenty seconds its true sine should be used as a factor in obtaining the correction in all cases where the distance is as great as two hundred feet.

This method of applying the repetition of measurement of angles to the establishment of prescribed points is shown on the accompanying paper of instructions for setting monument points. The writer's first use of the method was in establishing points in topographical surveying on a rectangular basis, in the summer of 1871, when the result of its use was so satisfactory as to cause its employment constantly since that time.

The repetition of measurement of angles in the manner described has been in constant use in the Department of Public Parks of New York City for at least twelve years, and, the writer believes, was previously used in the survey of Morrisania, and afterward in Long Island City, in Yonkers and other places. Its value is so great that no surveyor who has once become familiar with the system will willingly dispense with it where accurate work is required. This refinement of surveying, as it may be termed, is little better than farcical affectation if certain preliminary essentials are not observed.

Of these, one of the most important is the standard of measurement, and every engineer should endeavor to supply himself with one that is correct. Having obtained a measure that is believed to be accurate, it should be applied to the establishment of points that will be as nearly as possible unchangeable, so as to make a permanent standard for testing and correcting. This will make it possible to have all his work consistent with itself, even though he should not succeed in getting an absolutely correct standard.

The transit or theodolite must, of necessity, be correctly graduated, and be kept in good adjustment. Many instruments have been made with the plumb bob suspended from the head of the tripod; this may do for some work, but not for such as is described in this paper. The tripod head must be open, so that the plumb line can be attached directly to the instrument, and the plumb bob must be accurately turned.

In windy weather an essential for accurate work will be the shielding of the plumb line in setting the transit and in placing a line for measurement of angles, as well as in chaining over irregular ground, all linear measurements being made horizontal.

The last of these essentials to mention, although first in importance, is care in work, reliable chainmen being indispensable.

In angular measurements it will be well to always use the same vernier, and to always measure from left to right. An imperceptible movement of the instrument when turning the upper or inner plate will sometimes be indicated by the readings. This may be remedied or balanced by turning the glass toward the left for some of the repetitions. Where the first reading is as large as one hundred and fifty degrees the glass should be turned to the left as many times as to the right; but for one hundred and twenty degrees twice to the left will balance four times to the right, while for ninety degrees or under, once to the left will be sufficient for the six readings or repetitions.

The tests that have been hereinbefore described will not apply where tracts are not wholly enclosed; and it is, therefore, well that such strict accuracy is not ordinarily required in the survey of long lines, as for railroads or country highways; yet, even there, it will be of advantage to take two readings of each angle as a check against error.

An occasional noting of the magnetic bearing will also serve as a check that should be availed of, for in no profession can guards against error be less safely dispensed with than in that of civil engineering.

The amount of care that is taken in surveying is frequently governed by the opinion entertained regarding its reasonable cost.

The writer is acquainted with a surveyor, for whom he has a high respect as a worthy, conscientious man, who, though possessing an excellent transit with verniers reading single minutes, yet makes all his surveys by the needle, objecting to the use of the limb because "it would require the taking of back sights," which would make him feel as though he was "nursing the job."

For such surveying, even where not affected by local attraction, the amount of error allowed by Professor Gummere, of three links in ten chains, or three feet per thousand feet, is none too large.

A motto particularly worthy of acceptance by all engaged in the practice of the profession of civil engineering is "What is worth doing at all is worth doing well."

PLATE XXIV.
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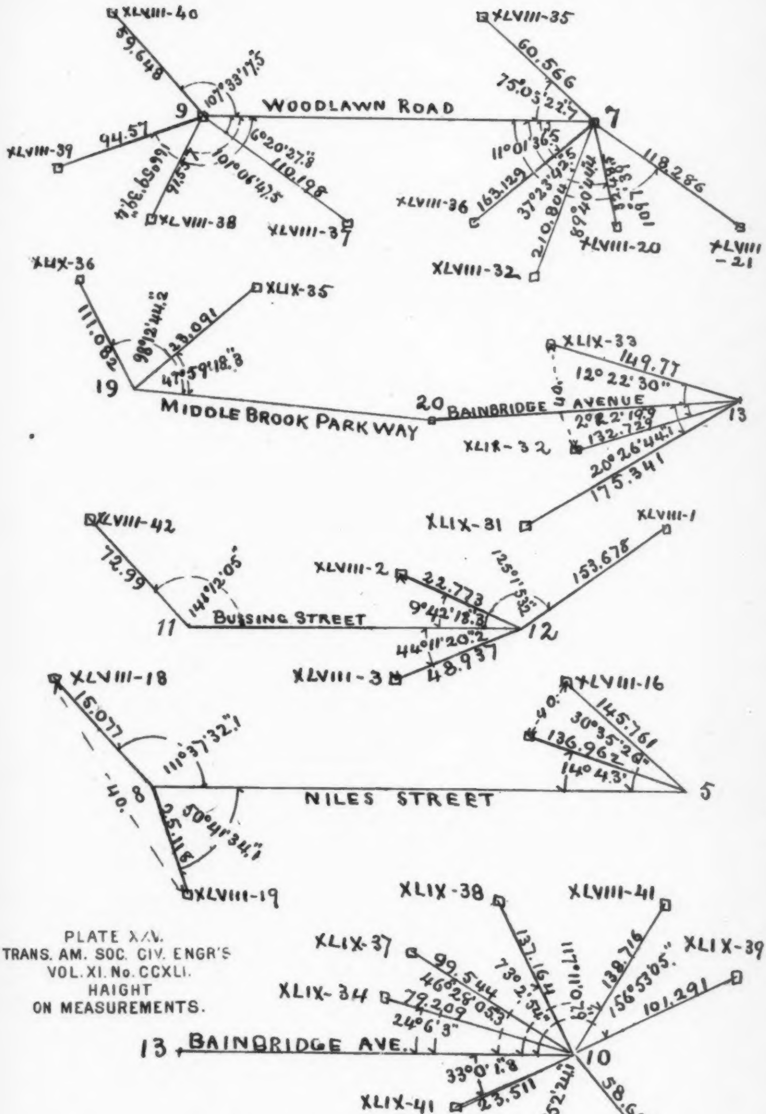

PLATE XXV.
TRANS. AM. SOC. CIV. ENGR'S
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HAIGHT
ON MEASUREMENTS.

CALCULATED POSITIONS
OF MOMUMENTS

Readings of Angles.

15*a*	44° 29′ 20″	1	143° 42′ 20″	1*a*	54° 38′ 20″
	6) 266 54 40		6) 862 14 20		6) 327 50 00
	44° 29′ 06″.7		143° 42′ 23″.3		54° 38′ 20″
2	107° 50′ 40″	2*a*	61° 07′ 20″	2½	59° 43′ 00″
	647 02 40		366 43 40		358 18 20
	107° 50′ 26″.7		61° 07′ 16″.7		59° 43′ 03″.3
3	80° 49′ 00″	3*a*	59° 09′ 40″	4	134° 48′ 40″
	484 54 20		354 57 00″		808 53 20
	80° 49′ 03″.3		59° 09′ 30″		134° 48′ 53″.3
4*a*	151° 21′ 20″	6	98° 10′ 40″	7	116° 54′ 40″
	908 08 20		589 03 40		701 28 40
	151° 21′ 23″.3		98° 10′ 36″.7		116° 54′ 46″.7
7*a*	129° 11′ 40″	8	124° 55′ 00″	5	126° 09′ 40″
	775 11 20		749 31 00		756 58 20
	129° 11′ 53″.3		124° 55′ 10″		126° 09′ 43″.3
9	99° 06′ 20″	10	89° 26′ 00″	10*a*	66° 20′ 40″
	594 39 20		536 37 20		398 04 00
	99° 06′ 33″.3		89° 26′ 13″.3		66° 20′ 40″
11	165° 25′ 40″	12	152° 24′ 00″	13	171° 05′ 00″
	992 33 20		914 24 20		1026 29 00
	165° 25′ 33″.3		152° 24′ 03″.3		171° 04′ 50″
20	53° 40′ 40″	15	152° 28′ 00″	16	163° 41′ 00″
	322 02 20		914 47 20		982 06 00
	53° 40′ 23″.3		152° 27′ 53″.3		163″ 41′ 00″
16*a*	70° 27′ 20″	19	179° 40′ 00″		
	422 42 40		1078 01 40		
	70° 27′ 06″.7		179° 40′ 16″.7		

Tests of Accuracy of Angular Measurement.

Block 942′.

< 2 = 61° 07′ 16″.7

2½ = 59° 43′ 03″.3

3 = 59° 09′ 30″

179° 59′ 50″

3 < —10″.

Block 941.

< 5 = 126° 09′ 43″.3

8 = 124° 55′ 10″

7 = 116° 54′ 46″.7

6 = 98° 10′ 36″.7

4 = 73° 49′ 43″.3

540° 00′ 00″

6 < No apparent error.

Block 942.

< 2 = 107° 50′ 26″.7

1 = 161° 39′ 16″.7

12 = 152° 24′ 03″.3

Supt. 11 = 14° 34′ 26″.7

10 = 89° 26′ 13″.3

9 = 99° 06′ 33″.3

7 = 113° 53′ 20″

Supt. 8 = 55° 04′ 50″

Supt. 5 = 53° 50′ 16″.7

4 = 151° 21′ 23″.3

3 = 80° 49′ 03″.3

1079° 59′ 53″.3

14 < —06″.7

Block 949.

< 1 = 54° 38′ 20″

15 = 163° 03′ 00″

16 = 125° 51′ 53″.3

19 = 179° 40′ 16″.7

Supt. 20 = 126° 19′ 36″.7

13 = 171° 04′ 50″

10 = 66° 20′ 40″

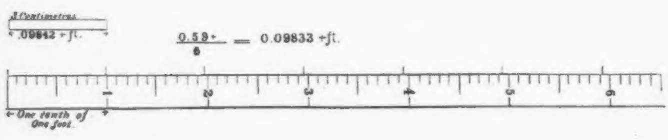
11 = 165° 25′ 33″.3

Supt. 12 = 27° 35′ 56″.7

1080° 00′ 06″.7

11 < + 06″.7

Block	928,	Errors	= —10″.0
"	941,	"	= 00″.0
"	942,	"	= —06″.7
"	949,	"	= +06″.7
"	942 and 942′,	"	= —16″.7
"	942, 941 and 942′,	"	= —16″.7
"	942, 942′ and 949,	"	= —10″.0
"	942, 941, 942′ and 949,	"	= —10″.0
"	941 and 942,	"	= —06″.7
"	942 and 949,	"	= 00″.0
"	941, 942 and 949,	"	= 00″.0



			Feet.			15= 0.00 N.	0.00 E.
15 to 1		North	393 635	393.635 N.			
< W. 36° 17′ 36″.7	—0″.2					1= 393.635 N.	0.00 E.
1 to 2		N. 36° 17′ 36″.5 W.	573.5	462.238 N.	339.466 W.		
< E. 72° 09′ 33″.3	+0″.2					2= 855.873 N.	339.466 W.
2 to 3		N. 35° 51′ 57″.0 E.	378.62	306 83 N.	221.83 E.		
< S. W. 80° 49′ 03″.3	—0″.3					3=1162.703 N.	117 636 W.
3 to 4		S. 44° 57′ 06″.0 E.	223.555	158 211 S.	157.944 E.		
< N. E. 134° 48′ 53″.3	+0″.2					4=1004.492 N.	40.308 E.
4 to 6		N. 89° 51′ 47″.5 E.	602.25	1.437 N.	602.249 E.		
< S W. 98° 10′ 36″.7	—0″.2					6=1005.929 N.	642.557 E.
6 to 7		S. 8° 18′ 49″.0 E.	410.435	406.122 S.	59.346 E.		
< E. 50° 48′ 06″.7	+0″.3					7= 599.807 N.	701.903 E.
7 to 9		S. 59° 06′ 56″.0 E.	405.24	208.014 S.	347.779 E.		
< W. 80° 53′ 26″.7	—0″.2					9= 391.793 N.	1049 682 E.
9 to 10		S. 21° 46′ 30″.5 W.	312.925	290.597 S.	116.084 W.		
< W. 24° 13′ 06″.7	—0″.2					10= 101.196 N.	933.598 E.
10 to 13		S. 45° 59′ 37″.0 W.	286.	198.696 S.	205.709 W.		
< W. 8° 55′ 10″.0						13= 97.5 S.	727.889 E.
13 to 20		S. 54° 54′ 47″.0 W.	340.12	195.508 S.	278.313 W.		
< N. W. 126° 19′ 36″.7	—0″.2					20= 293.008 S.	449.576 E.
20 to 19		N. 71° 24′ 49″.5 W.	152.045	48.461 N.	144.115 W.		
< E. 00° 19′ 43″.3	—0″.3					19= 244.547 S.	305.461 E.
19 to 16		N. 71° 05′ 06″.5 W.	272.635	88.378 N.	257.913 W.		
< E. 54° 08′ 06″.7	+0″.3					16= 156.169 S.	47.548 E.
16 to 15		N. 16° 56′ 59″.5 W.	163.33	156.234 N.	47.616 W.		
< E. 16° 57′ 00″.0	—0″.5					Errors. 15= .065 N.	.068 W.
< W. 28° 38′ 36″.7						4=1004.492 N.	40.308 E.
4 to 5		S. 16° 18′ 29″.3 E.	334.95	321.473 S.	94.055 E.		
< E. 53° 50′ 16″.7						5= 683.019 N.	134.363 E.
5 to 8		S. 70° 08′ 46″.0 E.	482.09	163.729 S.	453.436 E.		
< N. E. 124° 55′ 10″ 0						8= 519.29 N.	587.799 E.
8 to 7		N. 54° 46′ 24″.0 E.	139.58	80.512 N.	114.02 E		
< W. 63° 05′ 13″.3	—0″.3					7= 599.802 N. Errors= .005 S.	701.819 E. .084 W.
< S. E. 54° 38′ 20″.0	—1″.8					1= 393 635 N.	0.00 E.
1 to 12		S. 54° 38′ 18″.2 E.	181.43	105. S.	147.959 E.		
< E. 27° 35′ 56″.7	—1″.8					12= 288.635 N.	147.959 E.
12 to 11		S. 82° 14′ 13″.1 E.	497.62	67.217 S.	493.059 E.		
< S. 14° 34′ 26″7	+1″-8					11= 221.418 N.	641.018 E.
11 to 10		S. 67° 39′ 44″.6 E.	316.345	120.231 S.	292.607 E.		
< N. 89° 26′ 13″.3	+1″.8					10= 101.187 N. Errors= .009 S.	933 625 E. .027 E.
< N. W. 61° 07′ 16′.7	+3″.3					2 = 855.873 N.	339 466 W.
2 to 2½		N. 25° 15′ 23″.0 W.	376.465	340.478 N.	160.626 W.		
< E. 59° 43′ 03″.3	+3″.7					2½=1196.351 N.	500.092 W.
2½ to 3		S. 84° 58′ 30″.0 E.	383.915	33.627 S.	382.439 E.		
< S. W. 59° 09′ 30″.0	+3″0.					3=1162.724 N. Errors= .021 N.	117.653 W. .017 W.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

CCXLII.
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THE OVERFLOW OF THE MISSISSIPPI RIVER.

By LYMAN BRIDGES, Member A. S. C. E.

READ MARCH 15TH, 1882.

WITH DISCUSSIONS BY E. L. CORTHELL AND J. A. OCKERSON, MEMBERS A. S. C. E.

Much has been written, and many theories advanced by distinguished engineers, during the last twenty-five years, upon the levees, jetties and floods of the Mississippi.

This grand river, called the "Father of Waters," like the trunk of a tree whose branches extend from the Rocky Mountains on the west, to the Alleghanies on the east, and to Canada on the north, drains a water-shed of 1 147 000 square miles, extending over fourteen States, or an area nearly as large as the whole of Europe, with an annual downfall (exclusive of the Red River basin) of eighty trillions (80 000 000 000 000)

of cubic feet of water, and a drainage of twenty trillions cubic feet, or a ratio of twenty-five per cent. of the downfall per annum.

Admitting that the downfall and drainage are the same now as twenty-five or fifty years ago, new problems and new conditions present themselves.

The immense area of forest and timber lands cleared and the additional acreage placed under cultivation in the basins tributary to the Mississippi, necessarily change the rapidity of the drainage, and the increase of sediment in time of floods.

Another feature of no small moment is the gradual straightening of the river, which, during the last 160 years, has shortened its course 240 miles between Cairo and New Orleans; this increases the rapidity of the current and helps to overtax the levees below.

The vast swamps, bayous and lakes on either side of the Mississippi above the mouth of the Red River, are inundated and overflowed at the beginning of each season of high water, forming reservoirs for the surplus water of the river, thus relieving to a certain degree the lower Mississippi from its incapacity to carry off the water before it has reached the flood stage.

The great rainfall and water-shed of this river and its tributaries, equals a basin of water four hundred miles long, forty miles wide and 160 feet deep, and it would take the bed of the Mississippi, at the present rate of the current, three years to carry this water to the Gulf; or taking the ratio of 25%, which is universally admitted, had it an average daily drainage, it takes nine months of the year at its maximum to carry off this immense volume of water. But when we consider that the overflowed reservoirs on either side of the river, once filled, represent a volume of water nearly fifty miles in width and twelve feet deep from Cairo to New Orleans, or about twelve billions (12 000 000 000) of cubic feet of water, which would take the maximum capacity of the Mississippi eighty-four days to carry away, even though it had no reinforcement constantly forced upon it above, it is conclusive that no system of levees, below Red River, thus far constructed or proposed, can take away this yearly inland sea, having but 322 feet of fall from Cairo to the mouth of the Mississippi, and whose current is increased in flood stages from one-half mile an hour at medium stages to three (3) miles per hour and 1 000 000 cubic feet per second at flood stages. Some other means must be provided for the overflow above the

maximum capacity of the river. The principal levees are below the mouth of the Red River, and the capacity of the channel below that mouth has been largely increased by the costly levees on either side. It is compelled to attempt not only to carry off this immense volume of water, but in case of flood both above and upon the adjacent country through which it passes, it has always been taxed to its utmost capacity, and it has been unable to escape injury and expensive crevasses, inflicting untold injury upon the surrounding country.

Added to this area is the country tributary to the Red River, comprising an area of 97 000 square miles, with an annual downfall of 8 800 000 000 000 of cubic feet, and an annual drainage of 1 800 000-000 000 cubic feet of water.

The water from this immense additional water-shed, and the additional sediment necessarily carried down the Mississippi thereby, must be provided for in some other way. We are informed by Gens. Humphreys and Abbott, who gave years of study to this subject, that the mean annual discharge of the Mississippi proper was 19 500 000 000 000 cubic feet and 812 500 000 000 tons of sedimentary matter, constituting 241 feet in depth, one mile square, passing the mouth of the Red River annually.

When such is the case, the river must necessarily deposit a part of that sediment in the portions of the river the least direct, and thereby render the levees less efficient, until by a continual raising of the levees, the bottom of the river will be as it is in some instances now, above the level of the lands adjoining.

Over $100 000 000 has been expended in the construction of the Mississippi levees already.

During the past fifteen years over 100 miles of levees have caved in, and been lost to owners and the country.

How can we remedy the present evils and provide for the increased volume of water and future floods ?

We claim that the overflow has never been carried off by the Mississippi, and that its maximum capacity in time of floods never can be the medium or channel of the overflow at the flood stage, without many years of labor and great expense in deepening the river channel, and that the old natural channel or cut-off *via* the Atchafalaya River should be the main channel of relief aided by the Placquemine Bayou to the Atchafalaya, and the Bonnet Carré to Lake Pontchartrain.

The old channel of the Mississippi near the mouth of the Red River, near Williamsport, above Morgan's Bend, and the Atchafalaya River and Bayou from its connection with the Red River above its mouth, should be improved and a connection made with the old channel of the Mississippi through Latanache Bayou to Morris' Bay at Atchafalaya River and Bayou, thence through Bayou Alabama, Whiskey Bay and Grand River, Lake Rond and Grand Lake.*

Thence through Atchafalaya River to Atchafalaya Bay on the Gulf of Mexico. (See accompanying Plate XXVI.)

Also Grand River should be connected with Placquemine Bayou and the Mississippi at Placquemine, between Baton Rouge and Donaldsonville.

By this Atchafalaya River and Bayou route, it would be but one-half of the present length of the Mississippi to the Gulf of Mexico (from the mouth of the Red River), and only one-quarter of the distance by the Grand River and Placquemine route, and only about one-half of the distance would have to be improved, in either case, and the problem would be substantially solved, as the overflow would be confined to regular channels, and vast tracts of valuable lands reclaimed thereby. The elevation at mouth of Red River is 54 feet above the level of the Gulf of Mexico. Already steamers take the Atchafalaya route from Red River to Atchafalaya Bay, on the Gulf of Mexico, thus aiding commerce.†

A controlled communication can be opened by a system of locks of sufficient width and depth at the old channel of the Mississippi, near the mouth of Red River, below high water mark for the Mississippi, sufficient to receive 33 per cent. of the Mississippi. A system of locks above the mouth of Red River, with locks also in that river where the present channel would be turned into the Atchafalaya, would provide for navigation between the Red and the Mississippi. Continuing the channels to the Atchafalaya Bayou and River, and improving that and the other above mentioned bayous to Grand Lake, which would be but 50 miles, not only the surplus water of the Mississippi, but also all of the

* Already the overflow of the Mississippi and Red River have increased the channel of the Atchafalaya since 1850, between the bayous en route, from a width of 730 feet and a maximum depth of 52 feet, to a width of 1,200 feet, and over 100 feet in depth, or about 300 per cent. increase, and this in the face of everything being done to direct all the waters of the Mississippi and Red Rivers through the channel of the Mississippi.

† Recently Capt. N. Eastman took a steamboat from Chicago *via* Illinois and Michigan Canal and Mississippi River by this route to the Gulf of Mexico.


PLATE XXVI.
TRANS. AM. SOC. CIV. ENGR'S.
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BRIDGES
ON OVERFLOW OF THE
MISSISSIPPI RIVER.
MAP OF PORTION
OF THE
MISSISSIPPI DELTA
RED RIVER
OLD RIVER
PORT HUDSON
BATON ROUGE
PLAQUEMIN
MISSISSIPPI RIVER
LAKE MAUREPAS
LAKE PONTCHARTRAIN
BONNET CARRE
NEW ORLEANS

PLAQUEMIN
MISSISSIPPI RIVER
LAKE MAUREPAS
LAKE PONTCHARTRAIN
BONNET CARRE
NEW ORLEANS
ATCHAFALAYA BAY
GULF OF MEXICO
DELTA OF MISSISSIPPI RIVER

Red River (33 per cent. of the present water), would be conducted through this new channel to the Gulf of Mexico, in times of flood, for all time, at no greater expense than the cost of repairing the levees below the Red River for the present year. The locks at the mouth of the Red River and the sources of the Atchafalaya River can be controlled so as to turn all of the Mississippi and Red Rivers through the Mississippi at low water or when desired. The Grand River and Placquemine Bayou connection by sills with Grand Lake and the Mississippi would also assist in carrying off any local flood, and assist in case of extraordinary flood in keeping the water within the levees, in addition to which, the Bonnet Carré outlet 40 miles above New Orleans could be improved and controlled by sills, for emergencies and extra high floods, conducting surplus flood water into Lake Pontchartrain.

We claim that a regular controlled volume of water retained as nearly as practicable at its maximum, gives less friction, a regular or steady velocity, and consequently less deposits of sediment than by the present overtaxing of the levees. And crevasses are constantly occurring at all flood stages. At every crevasse bars form immediately below, and change the bed and slope of the river. This system of relief from the overflows is immediate, and would prove a great factor and auxiliary in any plan for deepening the river subsequently.

The mistaken idea that the overflows help to scour the Mississippi River is answered by the fact that the Mississippi only takes its maximum in any case, and a systematic control of the waste or present overflow does not affect the scour or jetties at the mouth of the Mississippi, to their disadvantage.

As more than half of the water that passes the mouths of the Mississippi escapes through other channels than the pass where the jetties have been constructed, if the permanence of the present jetties and ship channel depends upon the scour of the river, matresses or jetties can be constructed across the other passes, and this surplus water confined and turned through the desired channel.

In addition to the great benefits accruing to the country below the mouth of the Red River, these cut-offs would very materially reduce the height or depth of the Mississippi above the junction of the Red River, as far as Memphis at least.

Another beneficial result would accrue from the systematic control of the overflow; that of the health of the citizens living upon and in the

vicinity of these vast tracts of overflowed lands, who would escape the periodical epidemics, etc., that result from the miasmatic atmosphere generated by these overflowed lands.

The Mississippi River, with all its benefits to the commerce of the country, has never been completely surveyed by the United States, and maps made thereof, showing its main channel and tributaries. If this had been done, many of the citizens and sufferers by the present floods would have profited by such information, and comprehended the magnitude of this water question, and been better prepared to protect themselves.

A State like Louisiana, with an area of 43 000 square miles, one-half of which would derive great benefits from such improvement, and a people raising such immense crops of cotton, sugar, rice, tobacco, and sugar cane for molasses, etc., which are now jeopardized and uncertain, would thereby be protected, and their crops assured, to the great benefit of the State and nation.

A commission has recently been appointed to consider this and all other subjects pertaining to the commerce and improvement of the Mississippi River, and it is hoped that they will give this subject their careful consideration.

Discussion at the Annual Convention by E. L. Corthell, Member A. S. C. E.

Mr. Chairman :—Many of the principles and statements advanced in this paper, are so directly opposed to my own experience on the Mississippi River, that I cannot refrain from making a few remarks.

Those that are interested in, and have studied the phenomena of the Mississippi River, are divided into two camps ; one of which advocates the *Outlet* theory, and the other the *Jetty* theory, or rather the *Dispersion* and the *Concentration* theories.

The subject is of such vast importance, not only as an engineering question, but as regards the commercial and agricultural interests of the whole country, that it is necessary that the correct principles which underlie the improvement of the Mississippi River, should be thoroughly understood and appreciated. We must recollect at the outset, that the valley of the Mississippi which is drained by the main river, contains about 768 000 000 acres of the finest land on the face of the globe, enough

to make more than one hundred and fifty States as large as Massachusetts; that if populated as Belgium and the Netherlands are (which may be the case at some future time), it would contain 400 000 000 of souls—nearly one-half the entire population of the world.

This river, on the improvement of which engineers are so radically divided, is really the great artery of the Republic; its branches envelope the great body of our country, and through its channel for all time to come must circulate the sustenance of our people. There is no doubt that the commerce of this great empire of the Mississippi valley, will in time exceed that of any other in Christendom. The channel which is, and must continue to be the natural highway not only of intercommerce among the states, but with the world outside, must have applied to it the correct principles of rectification.

As between the two camps mentioned, my experience on the Mississippi River and its mouth, compels me to join myself to those that advocate the *concentration* of the waters for the purpose of deepening the channel. The paper which we are discussing, advocates the *dispersion* of the waters.

Before commencing the discussion of the subject it is necessary to state to the Convention, that the laws which govern the flow of waters and the regulation of that flow in rivers whose waters are clear, are entirely different from those we find in waters filled with sedimentary matters. However experienced and learned the engineer may be in the improvement of the clear-water streams or rivers, he finds when he commences upon the improvement of sediment-bearing rivers that he has new principles to deal with and new problems to solve, new and strange conditions meeting him at every turn. It will be necessary to divest ourselves of much of the experience we have gained in clear streams in order to fully appreciate the difficulties in the way of the improvement of a river like the Mississippi whose waters are more or less charged with sediment; we not only have the waters to contend with, but the fine detritus, which has come into the main channel from its innumerable tributaries, from mountains and plains whose rocks and soils are diverse in character. These heavy particles or washings from mountain and plains, being borne to the sea by the current which, by its velocity and its irregular motions suspends and carries forward its load, complicates the question of the improvement of the channel. The laws which govern the currents and the motions of the sediment are as variable as those

which govern the currents of clear water streams, but we find that all the forces of sediment bearing streams are in such perfect and delicate equilibrium, that the slightest attempt by man to disturb this equilibrium is liable to cause injury rather than benefit to the channel if the laws and forces are not throughly understood. We have noticed this particularly in our experience at the head of the passes of the Mississippi River, where in order to deepen the channel from the main river into the South Pass it was necessary to disturb this equilibrium of the current and sedimentary forces. The natural conditions existing there were so delicately adjusted, that any artificial change in any one of them produced changes in all the others either for good or evil; in fact there is not anything in nature more sensitive than the delicate adjustment of these mighty forces.

It was my hope that we would be able to listen this evening to a discussion on this paper by Captain Jas. B Eads, Vice-President of the Society; he, we all know, has had many years of experience in the improvement of the Mississippi River, and has given the subject careful consideration and study, but sickness prevents his attending the Convention, and it is by his wish that I present not only my own views but his also, with which I most decidedly agree. He has handed me a paper which is a report to the Mississippi River Commission, and which contains not only his own views but those of the Commission also. The views are so clearly and concisely expressed and are also so exhaustive that I ask permission of the Convention to give them. The remainder of my discussion of the subject will therefore be extracts and abstracts from, and my comments on, this report.

It is generally known that the Mississippi River Commission, as soon as the necessary means were placed in its hands, went at the work in earnest to obtain the facts from which could be deduced the laws which govern the flow of the river, and which should become the basis for its proper improvement. From Cairo to New Orleans their hydrographic and topographic and levelling and transit parties have carefully gathered together a great many, if not all of the facts that are necessary for the purpose of studying the subject. The most careful and patient observations have been made by their parties to ascertain the effects of crevasses and outlets, and also levees, dikes and jetties. The observations made by the Commission plainly show that the effects of crevasses and gaps in levees have been to raise the flood line of the river

above any height previously attained; and the observations further show that between Natchez and the mouth of the Ohio River the deposits of sediment, due entirely to these crevasses and gaps in the levees, have raised the bed so much as to injure navigation.

We will now state the general principles which underlie the plan of improvement recommended by the Commission, and which were the result of the observations made, the facts obtained, and the thorough and close study given to these facts.

The region of country which we are contemplating, and through which the present channel of the Mississippi runs, was no doubt in earlier times a wide and deep estuary of the Gulf of Mexico. By the breaking through of a spur of a mountain range the sedimentary matters from the upper rivers gradually filled up this basin with rich deposits, until now we have a plat of land about sixty miles wide and six hundred miles long, in a direct line, containing about 34 000 square miles. The floods of the river gradually raised the whole basin so that near the head of this ancient estuary the elevation of the land is about 300 feet above the sea. The surface of the land has a quite regular descent from the upper end of the basin to the gulf. Through these deposits the river winds its tortuous course in a channel about 1 150 miles long. Experience and observation prove most conclusively that the quantity of solid matter which the water of the river is able to hold in suspension is strictly regulated by the velocity of the current. Therefore, during the natural process of this land formation, whenever the flood waters escaped over the banks of the channel, the loss of current in the water thus escaping caused the sandy or heavier portions of the solid matter held in suspension in it to settle almost immediately on the submerged banks, while the argillaceous and lighter portions, which take longer to settle, were carried back by the feebler current to the swamps or lower lands on which they were deposited over a much more extensive area. These lighter matters now constitute the blue and other colored clay strata which are found in all parts and all depths of the basin. The river banks were thus kept constantly higher than the lands more distant from the stream. Before any levees were built on them they were usually from ten to fifteen feet higher than the lands one or two thousand yards distant from the river.

The size of the flowing volume of any river constitutes, as will be seen hereafter, a very important element in determining the velocity of its

current, and as the loss of volume over the natural banks has the effect of producing a more sluggish current in the main channel, a deposition of sediment resulted wherever this loss occurred.

In this manner the bed of the stream, during each successive flood, was built up higher and higher, while the water escaping over the banks built them up also. Thus the river and its banks were both gradually elevated above the neighboring lands until some important breach occurred in one or the other bank and caused the river to seek a new channel through or over the lower lands. Illustrations of this process are frequently occurring at this time in the lower part of the basin. Sixty miles above the mouth of the river its flood surface is now seven or eight feet higher than the mean level of the gulf, and through this sixty miles it flows to the sea between narrow banks that have been elevated by repeated overflows above the sea level. From time to time the river has broken through these narrow embankments and found a steeper and shorter route to the salt water. Through such new route its heavily laden waters bear immense quantities of sediment which is deposited in the gulf at the mouth of the outlet, because the current can carry it no further.

About thirty-five miles above the mouth, one of these outlets known as "The Jump," occurred about forty years ago. It has already formed over a hundred square miles of territory upon which rice plantations exist, and on which trees are growing larger than a man's body. From six thousand acres of this land purchased from the State of Louisiana, were obtained nearly all the willows used in the construction of the jetties. The gradual enlargement of this sub-delta has so lengthened the outlet and flattened the surface slope of its branching channels, that the current from the river through them, even in flood time, is now too sluggish to carry the heavy sedimentary matters of the main river by that route to the sea, and hence this outlet is gradually closing up. When it first occurred the water in it was one hundred feet deep; now it is scarcely four or five.

The extensive crevasse, called "Cubits Crevasse," about three miles above the head of the passes, is another illustration of the foregoing principle, that although the river often breaks through its narrow banks to find a shorter passage to the sea, it is only a temporary outlet which the river itself commences at once to fill up by the deposition of sediment. At first the flow of the water into the gulf is unobstructed, but it requires

only one season's flood after the crevasse has formed to make quite a bar between the crevasse and the gulf, thus obstructing the flow of the current, and causing more deposits to be made upon this new formed bar, which gradually encircles the crevasse on the outer side and fills up new banks in the distance, which, after a while, become overgrown, still further obstructing the flow of the current and causing still further deposits; soon after a heavier growth of bushes and trees springs up, islands are formed, between which are found narrow channels which perhaps for some time are navigable for small boats, but which are eventually closed by the frictional resistance which this sub-delta everywhere offers to the free flow of the water, until at last nothing but a slight indentation of a continuous river bank is left to mark where an extensive crevasse occurred many years before. These marks or indentations, hardly perceptible, are, as it were, scars or wounds which were inflicted upon the river, but which it set itself at work to heal the moment they were made.

At the Bonnet Carré Crevasse the same results are seen, even without any artificial dam across the mouth of this crevasse, the river had already commenced to close up the outlet and would eventually have done it completely even if artificial help had not been given it. The same is true of all other outlets, unless it may be the Atchafalaya, which no doubt was at one time the main channel of the river, and into which the river would at present pour its whole volume if the conditions were right for it. These crevasses, cut-offs and outlets have, during the history of the river, facilitated the distribution of the sedimentary matters for the benefit of agriculture. In the advanced state of the country, with the present condition of agriculture, and our population, it is wise to consider this great basin as a heritage from the river, which it is our duty to utilize for the good of the country. The facts, based upon observation and experience, show us that the proper way to utilize this land formerly overflowed by the river is to confine within its natural channel the whole volume of water; this we can best and most easily do by means of levees or embankments, built along the edge of the river. But we will, at the same time that we prevent the overflow of the floods accomplish a still more necessary result, and one more extensive in its influence, and that is the deepening of the channel of the river, so that from New Orleans to Cairo there will be a channel deep enough at all seasons of the year for the deepest draught boats. It has often been

stated, but erroneously, that levees tend to raise the bed of the river. The contrary is true, for levees deepen the bed of the river and outlets and crevasses always raise it, not only upon the Mississippi River but on the Po and Rhine and other rivers of Europe. The history of levees and embankments effectually disprove the statement that the bed of the river is raised by these works. The channels deepen and the floods lower as a consequence of perfect and thorough leveeing, and this, as we will see, is an inevitable result of the laws which control the phenomena of sedimentary streams where they flow in channels made through their own deposits. These principles or laws are very clearly stated in the language of Captain Eads, and I give them following :

"The term 'slope of the river' is used by engineers to indicate the inclination which the surface of the flood bears to the sea-level. When '*the slope*' is referred to without qualification, it means the *flood line* at the various points along the river, and is synonymous with the term 'the fall of the river per mile.' It has no reference to the slope of *the bottom* of the river. One end of the slope is unalterably fixed by the Gulf of Mexico. Other points in its line may be lowered or elevated to a certain extent by natural or artificial causes.

"The force which produces the current is the *fall of the water* from a higher to a lower level, and the slope is an indication of the amount of this force. Other conditions being the same, the steeper the slope the more rapid will be the current.

"The chief element which retards the current is the *friction* between the water and the bed of the stream. This friction increases as the surface in contact with the water increases, and is, therefore, greatest where the width is greatest, and conversely it is least where the width of the channel is least. Hence it is evident that the velocity of the current may not only be increased by increasing the slope, but also by decreasing the friction. It must be remembered that nearly all of the sedimentary matter transported by the water is carried *in suspension*, and that the quantity carried is in proportion to its velocity. Only a small quantity of it is rolled along the bottom. Hence if the current be checked when its waters are heavily charged with this sediment (as they always are in flood time), *a deposition of a portion of their burden becomes inevitable.* No fact in connection with the river is more thoroughly established than that *the current in flood time cannot be checked in the slightest degree without causing a deposition of some part of the sediment.*

Screens of iron wire with meshes one foot square, placed across shoals in the Missouri River, have sufficed to retard the current enough to cause deposits sixteen feet deep to be formed during one flood, and in this simple manner new banks have been developed in excessively wide parts of that river to deepen its channel and lower its slope. Willow screens, first used at the jetties at the mouth of the river, for the same purpose, raised the bottom during one flood, over a large area at the head of the passes where it was from twelve to sixteen feet deep, almost to the surface of the water, and 70 or 80 acres of land covered with vegetation are now to be seen on the eastern side of the upper end of the South Pass channel that has been thus formed.

"I have named three controlling principles which are present in every problem presented by the characteristic phenomena of the river. Each one of these is very simple in itself. It is, however, absolutely necessary to remember each of them to fully comprehend the subject, and to be able to recognize the respective influence of each in creating these phenomena. I will briefly repeat them to more strongly impress their importance. The *first* is the force producing the current. This force is simply the result of the fall of the river from a higher to a lower level. The *second* is the frictional resistance of its bed. The *third* is the intimate relation between the quantity of sediment carried in the water and the velocity of the current. If we increase or decrease the current from any cause, we increase or decrease the quantity of sediment carried by the river. We can increase or decrease the current temporarily by either of two methods; namely, by altering the slope, or by altering the frictional resistance. Therefore, by these two methods the scouring and depositing effect can be produced. If we increase the current during the floods we produce a greater deepening and enlarging of the channel through the shoals, and they are left in better condition during low water, and at the same time we ultimately lower the height of the floods. If we decrease the current we produce shoals and higher floods.

"The river, from Commerce to the Gulf, between the levees, is simply a grand trunk into which is poured all of the sedimentary matters of the tributaries. This trunk must discharge as much sediment as it receives, or that which it does not discharge must be left in the channel and thus injure navigation. If it discharges more than it receives, the excess must be taken out of the bed of the channel, and it will

be deepened thereby and the floods will be lowered. Hence it follows that by the process of deposit, or scour, the river has the ability to produce a current capable of carrying its sedimentary burden, without loss or gain, to the sea. This velocity of current we may call the *normal* current. In seasons of great floods the *normal* current will be more rapid than when the waters are less highly charged with sediment. This normal current is produced by the river itself as a result of these three controlling principles. Flowing over a bed of deposits from which it takes up additional sediment when the current is too rapid, it thus deepens the bed, and with it the slope, and thus the current declines. If it be too sluggish, deposits fall to the bottom and by raising the bed it increases the slope, and as this is steepened the current is accelerated until the normal velocity is again attained. It follows, therefore, that it is not in the power of man to *permanently* increase its current above the normal velocity. If it be increased from any cause, the water will take up an additional burden from the bed of the river and thus enlarge and deepen its channel, and its slope will be thereby reduced, and with this reduction will follow a reduction of current and the scouring will cease as the current diminishes until the normal rate is attained, and then the channel will be sufficiently enlarged and the slope so lowered as to prevent any further scouring.

"The importance of the levees as a means of improving the navigation of the river comes wholly from the relation which the volume of a sedimentary stream bears to the frictional resistance of the bed. If the volume be diminished, the ratio of friction to the volume will be increased; and, conversely, if the volume be increased, the ratio of frictional resistance will be decreased. Hence, if it can be shown that a higher velocity of current results from the retention of the whole volume within the levees, it must follow that a greater amount of sediment will be transported, and if this amount be greater than that which the tributaries contribute, it must be taken up out of the bed to the benefit of navigation, and the flood line must consequently be lowered to such a degree as will finally reduce the excess of current which the increased volume has produced, down to the normal velocity. The increase of volume which will be secured by the closure of these gaps will produce this increased current.

"Through these a large part of the volume of the floods now escapes, and this force the river is expending in its prehistoric occupation of

land building—a process wholly incompatible with the occupation of this vast alluvial district by man. Instead of letting this worse than wasted force be thus employed, the plan recommended by the Commission proposes to utilize the entire force of the river to deepen its channel for the safe transit of the immense products of the valley, and for the safe discharge of its entire volume of flood waters without interrupting in any manner the avocations of commerce and agriculture. That it is entirely practicable to retain within the present levees the entire flood discharge of the river, if they be repaired, even without raising them any higher, I will now endeavor to prove.

"The relation which the volume bears to the frictional resistance will be readily understood by examining the diagram, Plate XXVII. Let us suppose the Mississippi River in flood to be 118 feet deep and 3 000 feet wide, and that an additional rise of 5 feet then occurs. The increase of friction in this case is only on the two sides of the channel which are in contact with this additional 5 feet of depth. This frictional or wetted surface on the two banks would probably not exceed an aggregate width of 20 feet. The water flowing in the stream before this addition was made to it had a frictional surface of about 3 100 feet in width. The 5 feet additional rise increases the cross-section in such case from about 200 000 to 215 100 square feet, or 7½ per cent., while the friction will have been only increased about two-thirds of 1 per cent.

"We see, therefore, that the ratio of friction decreases with an increase of volume, and, as a natural result of this, we must have an increase of velocity of current, and, consequently, an increased capacity of discharge in the stream. But, in addition to the increase of velocity from the diminished friction, the five feet elevation materially increases the slope also, and thus adds another cause to increase the current. Carrollton is 120 miles from the Gulf; therefore a 5-feet rise there increases the slope ½ an inch per mile.

"The semi-circular diagrams are intended to show how rapidly the frictional resistance increases if the river be divided into two or more channels. The large semi-circle may be supposed to represent the bed of the main river, its capacity being equal to that of the two smaller ones. The wetted surface or frictional resistance is increased by this subdivision 41 per cent. Hence it is simply impossible for the water to flow as fast in two channels, unless they have steeper slopes, as it would if it all flowed in one channel.

"Some idea of the immense increase in the capacity of the river to discharge its floods, as a result of this reduction of friction and increase of slope, may be inferred from a few facts I have tabulated from the exact measurements of Humphreys and Abbot during the floods of 1851 and 1858. They are excerpted from Appendix D of their report. These measurements were made at two places on the river nearly 1 000 miles apart, and when the floods were confined within the levees.

FIRST—AT COLUMBUS, TWENTY MILES BELOW CAIRO.

1858.	Height in feet.	Discharge per second in cubic feet.	Mean velocity in feet.
June 15, 1858, height of river above low water	40.1	1 349 400	8.19
June 28, 1858	38	1 156 960	7.22
Difference	2.1	192 440	.97

SECOND—AT COLUMBUS.

June 15, 1858	40.1	1 349 400	8.19
July 1, 1858	33.3	841 487	5.62
Difference	6.8	507 913	2.57

THIRD—AT CARROLLTON, NEAR NEW ORLEANS.

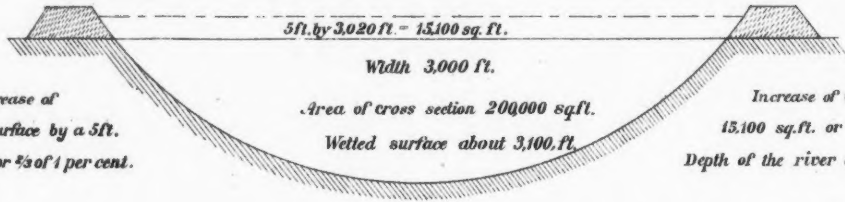
February 24, 1851	11.8	894 491	5.04
March 17, 1851	14.8	1 152 504	6.22
Difference	3.0	258 013	1.18

FOURTH—AT CARROLLTON.

February 21, 1851	10.1	766 497	4.41
March 8, 1851	14.1	1 068 464	5.81
Difference	4.1	301 967	1.40

PLATE XXVII.
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XI. No. CCXLII.
CORTHELL
ON
MISSISSIPPI RIVER.

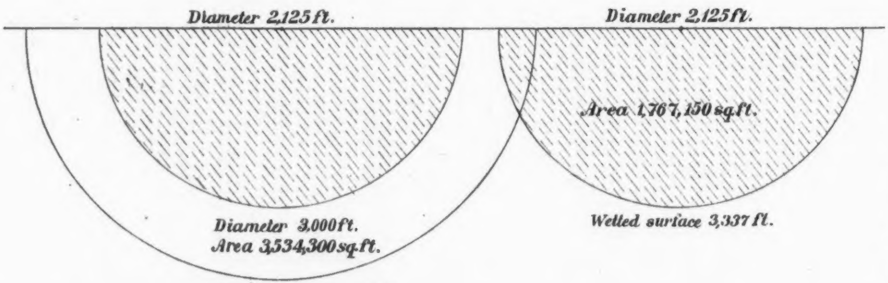
APPROXIMATE SECTION OF THE MISSISSIPPI AT CARROLLTON



Increase of wetted surface by a 5 ft. rise = 20 ft. or ⅔ of 1 per cent.

Increase of volume by a 5 ft. rise, 15,100 sq. ft. or 7½ per cent.

Depth of the river about 120 ft. at the lower level.



Wetted surface of the two smaller circles 6674 ft., or 41 per cent. more than the one large circle.

Aggregate area of the two small circles only equal to that of the large one.

FIFTH—AT CARROLLTON.

March 19, 1851	14.9	1 149 398	6.19
August 25, 1851	8.1	572 388	3.38
Difference	6.8	577 010	2.81

"We see by the first table that when the river at Columbus was 83 feet above low-water mark an additional rise of only 2.1 feet was sufficient to increase the mean current nearly one foot per second, and that the discharge was one-sixth greater. The depth of river at the time was about 96 feet. Therefore this 16 per cent. increase of discharge was attained with the addition of only one-fortieth part of its depth.

"The second table shows that a decrease of 6.8 feet in the height of the river at this place resulted in a loss of more than 2½ feet per second in the current and a diminution of 508 000 cubic feet per second in the discharge. If we suppose the banks of the river to have been 90 feet above the bottom of the channel, this table proves that with levees only 7 feet high upon them, they would retain a sufficiently increased volume to add 60 per cent. to the discharge of the river, and over 45 per cent. to the velocity of the current.

"The third table shows that at Carrollton, near New Orleans, an increase of 3 feet in the height of the river added nearly 30 per cent. to the amount which was discharged, (almost doubling the percentage of increase shown with a rise of 2.1 feet at Columbus,) while the current was accelerated at the same time more than 20 per cent.

"The fourth table shows that at four feet greater height of the river it discharged 40 per cent. more water and that its current was increased 32 per cent.

"The fifth table shows that with a difference of only 6.8 feet the discharge of the river at Carrollton was more than double. The river here at the lowest stage was 115 feet deep. Hence there was an increase of only one-seventeenth part of its total depth required to produce this astonishing difference in the discharge of the river. The velocity was at the same time increased 85 per cent.

"These tables are the result of actual observation and careful measurements. They represent stubborn facts, without any theorizing, and they show how absurd are some of the statements made as to the effect of outlets in lowering the floods of the river. For instance, the fifth table

shows that when the river, (March 19, 1851,) was nearly up to the highest water-mark known at Carrollton, it would have required an outlet larger than the Mississippi itself to lower it 6.8 feet. Such outlet would have had to discharge 577 000 cubic feet per second, while the whole river could only discharge 572 000 feet, when its surface was 6.8 feet lower. This enormous quantity of water (577 000 cubic feet per second) would cover a square mile one foot deep in about forty-eight seconds, in twenty-four hours it would cover 1 800 miles to the same depth, and in less than a fortnight it would put an average depth of three feet over an area as large as the entire State of New Jersey. To lower the river only two feet at Carrollton when in flood, would require an outlet as big as Red River. This is because such loss of volume lowers the slope and increases the frictional resistance in the main stream below the outlet; and this causes it to flow more slowly, and thus prevents that great reduction in its height which the thoughtless would expect.

"When we refer to the three principles governing this problem and know how thoroughly they are established by experience, observation and experiment, and remember the intimate relation existing between the *quantity* of sediment carried and the *velocity* of the current, it would seem impossible to arrive at any other conclusion than that the loss of velocity, which invariably accompanies a lower height of the flood line, cannot fail to result in a deposition of sediment in the channel of the river, where such loss of velocity occurs during a flood when the water is carrying such an enormous volume of sediment. But this fact does not rely for proof upon the plain deductions to be drawn from a consideration of the three principles we have referred to. The numerous soundings and examinations made of the bed of the river show that below every outlet its channel is reduced in size by the deposits thrown down as a result of the loss of volume through such outlet and the consequent reduction in velocity of current.

"The floods do not come so suddenly but that the increased velocity due to the increased volume is felt many days before the floods rise near the top of the levees, and if these gaps were closed I have no doubt that the increased velocity resulting therefrom would enable the floods to be discharged without any danger of their overtopping the present levees. It is possible that some very extraordinary flood, if it occurred the next year after they were closed, might break through them or escape at some one of the lowest points in them; but extraordinary floods are excep-

tional, and it is altogether possible that before another one comes the channel of the river would be restored to the dimensions which it had when these levees were intact, and when they were capable of discharging any one of the ordinary floods which occurred.

"If they be left open, new shoals and injurious changes in the channel will be occurring at other points of the river than those selected by the Commission for immediate improvement, and these new obstructions and changes in the channel will require so much more additional work, and this will undoubtedly cost twice or thrice as much as it will to repair the levees. By repairing them the channel will not only be prevented from becoming worse at any point on the river, but the shoaling which has occurred as a result of these outlets will be removed by the effect of the levees, and the works of improvement can then be limited to the reduction of the excessively wide places which now exist, and which are enclosed by the present lines of levees. These wide places are the cause of cut-offs, caving banks, shifting channels and vexatious shoals.

"The plan of improvement recommended by the Commission differs from any other previously proposed for the correction of the channel, in the fact that it looks to a rectification of the *high-water channel*, by the ultimate narrowing of these wide places, as the *only* method by which a deep and uniform low-water channel can be permanently secured."

Mr. Bridges advocates the outlet theory by utilizing bayous and the present outlets, some of which he enumerates. From the foregoing statements or principles that govern the flow of water, and from the observations made by the Commission in its examinations it is very evident that if we apply practically, or attempt to apply, this outlet theory to the Mississippi River, we will certainly raise its bed and increase not only the extent but the frequency of its overflows, and, still further, will fill the channel of the river with shoals and sand bars.

The Mississippi River Commission in a report dated Feb. 17, 1880, very clearly states why the above named results will follow the dispersion of the waters of the Mississippi River by means of crevasses and other outlets.

"It is a well established law of hydraulics that the ratio of frictional resistance per unit of volume increases if the sectional area be diminished. Thus, if the volume of a river were suddenly divided by an island into two channels, the water flowing in them would encounter

more frictional resistance than it met with while flowing in a single channel. Hence the currents through these channels would be more sluggish, and as the water is charged with sediment, the sluggish current would cause a deposit in the channel which would first begin at the upper ends, and would continue until the bottoms of the two channels would be so steepened, that the current would attain a velocity capable of carrying the suspended sediment through them without further deposit, and the slope of the river's surface in flood time would be found to be steeper through them than above and below, where the volume flows in a single channel.

"In the case of a crevasse, an island is also formed having the main body of the river on the one side and the crevasse channel on the other side. As the volume flowing in the main channel below a crevasse has been decreased by the amount drawn off through it, a steeper slope in the main river, if the crevasse be kept permanently open, becomes inevitable, because the shoal below the outlet as it grows in length down stream, from the deposition of successive floods, gradually increases the frictional resistance of the volume flowing through the diminished channel, and this tends to check the current of the river *above* the crevasse, and thus the shoaling of the river bed and the raising of the flood line above the site of the outlet ensues as a secondary and permanent effect.

"It is in this way that silt bearing streams flowing through alluvial deposits have the ability to increase or steepen their surface slopes and thus recover the velocity of their currents, and adjust them to the work of transporting the sedimentary matter with which the flood waters are charged, so that this matter may be carried without loss or gain.

"In proof of the correctness of these views, and of their full accordance with well-established hydraulic laws, we have the evidence of this relation between slope and volume presented in the phenomena of silt bearing streams all over the world. Whenever such streams flow through alluvial deposits, other conditions being the same, the slope is least when the volume is greatest, and conversely the slope is found to be "invariably increased as the volume is diminished."

The truths above mentioned are capable of complete demonstration and are generally recognized by hydraulic engineers, and the effects of opening new outlets and enlarging present ones will result in still more injury to the channel, and still greater and more destructive overflows

to the whole alluvial region. On the other hand, there is no doubt (for we have facts to prove it) that a concentration of the flood waters of the Mississippi River will decrease the flood heights, for the slope will be reduced by the increase of volume, as it is stated by the commission that "the slope is found to be invariably *increased* as the volume is *diminished.*

Careful examinations show that, in the *Atchafalaya*, by the increase of its volume (and that a very large increase), there has been a decrease of elevation; but on the other hand, in the Mississippi *no decrease of flood height has been observed*, although a large volume has been abstracted from the main river by this outlet. The gauge records at Natchez, Red River and Baton Rouge, show this to be a fact, although the abstracted volume practically amounts to the diversion of a tributary with about one-sixth of the flood discharge of the Mississippi River. That is to say, the Mississippi below the Atchafalaya is to-day carrying *one-sixth less than it did formerly, and yet no diminution in its flood line is observable at these points below the outlet.*

No better evidence could be given than the fact that the bed of the main river below the Atchafalaya has gradually been filling with so much deposit under the influence and effects of the Atchafalaya that only five-sixths of the former flood volume is all that is now required to bring the surface of the floods to the same height on the levees that they attained when the main river received the volume of Red River.

Another important and deleterious effect of outlets is the raising of the river bed above the outlets, for in order to obtain the necessary increase of slope to carry a small volume in the main river, the bed of the river must necessarily be raised above the outlet as a secondary result. This theory is established by the observation of facts.

From the foregoing statement of principles and facts, and from the result of studies which have been given them by experts in river hydraulics, it is very evident that the only practicable and proper method by which to permanently deepen the channel of the Mississippi River within its alluvial basin, is to concentrate the volume of its flood waters by confining them between embankments, and by these means to prevent the dispersion of the forces which alone have the power to abraid and deepen the river bed. This deepening also will result in a rectification and widening of the channel, and will give the flood waters room for their flow, will lower the flood slope of the river, and no doubt

in time will (if a perfect and thorough levee system is carried out) reduce the flood surface to such an extent that the overflow can be easily provided for, and the alluvial region saved from periodic overflows which have been so deleterious to the agricultural and commercial interests of this great district.

The subject we have discussed is one of great importance to us as citizens, as well as engineers, and we should give it the study it deserves, for the influence of this Society upon the important questions of internal improvement is very great.

Discussion by J. A. Ockerson, Member A. S. C. E.

In view of the discussion brought out by the paper on the "Overflow of the Mississippi," read by Mr. Lyman Bridges at the last Annual Convention, the following statements may be of interest. The facts given are deduced from a long series of observations and surveys made under the direction of the Mississippi River Commission.

It is well known that the Atchafalaya has been increasing in size for some time and now it carries off about one-sixth of the flood discharge of the Mississippi. The gauge at Natchez, however, shows that there has been no decrease in the flood height of the river below the outlet. This would seem to be conclusive proof that outlets will not afford relief from overflow. But there is a still more simple and obvious fact which can be verified during any flood by watching its progress as indicated by gauge readings at various points between Cairo and New Orleans. There can be no outlets above the mouth of the Red River in consequence of the bluffs which approach the river at Memphis, Helena and Vicksburg. Now, even if an outlet, as the Atchafalaya, *should* tend to lower the flood line in that vicinity, there still remains the simple fact, that long before the flood wave reached the outlet, the entire valley from Cairo to the Red River, a distance of 800 miles, would be submerged. It is impossible for the water to run out till the outlet is reached, and by that time the mischief has been done throughout the section lying above it.

In the discussion of the paper it was stated that "the current cannot be slackened in the *slightest* degree without depositing a part of its sediment." If this be true then the river must *always* be fully charged with sediment. That is, it must always carry as much sediment as the

velocity of the current can support. An examination of the following table will show how far the above statement is true.

Date.	Velocity Ft. per Sec.	Sediment Parts in 1 000.	Date.	Velocity Ft. per Sec.	Sediment. Parts in 1 000.
1879.		Gauge 163			Gauge 181
Nov. 30....	3.1	48	Feb. 18.....	6.7	112
Dec. 2......	3.2	90	April 9.....	6.3	74
1880.			May 4......	6.6	202
Aug. 16.....	2.7	104	May 12.....	6.2	54
		Gauge 179	July 10.....	6.2	232
Jan. 28.....	5.9	47			Gauge 185
April 17....	5.7	127	Jan. 26	6.3	53
July 8......	6.0	207	Feb 23......	7.3	79
		Gauge 181			
Jan 1.......	6.4	184			

It will be observed. 1st. That the amount of sediment carried at the same stage is not the same. 2d. That the most sediment is not necessarily carried at the highest stage. 3d. That the most sediment is not always carried at the highest velocity. It must be evident then that the river is not always fully charged with sediment. The amount of sediment carried, must depend on the amount *supplied* from erosion of banks and other sources as well as on the amount the current is *able* to carry.

Now inasmuch as the river is not always fully charged, the current *may* be slackened to a certain extent without reducing a deposit of its sediment.

The wire screens with meshes one foot square, used in the Missouri, caused a deposit of sixteen feet deep. The wire itself however did not obstruct the current sufficiently to induce this deposit, but the meshes were first clogged with weeds, brush and other debris which floated against the screen.

DISCUSSION BY LYMAN BRIDGES, MEMBER A. S. C. E.

The subject under discussion is "The Overflow of the Mississippi River." While we agree in many particulars, with the well defined merits of the Concentration theories, we insist upon confining this discussion to the subject under consideration, namely, the Overflow of the Mississippi.

The Dispersion theory is not applied in this case until the maximum capacity of the river is reached and passed; then a controlled overflow is proposed, at flood stages, of the volume of water above the maximum capacity of the river, thus keeping the steady volume and regular current at the maximum. This certainly promises greater stability and more regularity in retaining the channel of the main river than is accomplished by having large crevasses breaking through the levees and thereby, in many places, reducing the river from its maximum slope.

In the discussion, the main question seems sometimes quite lost sight of, namely, what shall be done with the overflow of the Mississippi, over and above the maximum capacity of the river in flood stages.

The Chief of Engineers of the United States Army recently stated before a committee of Congress, that at least $50 000 000 would be required to build levees below the Red River, and $50 000 000 more would be required above that point; thus making necessary an expenditure of at least $100 000 000 before it could be hoped that the present waters of the Mississippi could be confined within the levees.

We claim that the equilibrium of the sediment would not be as much interfered with by keeping the river at its maximum by means of controlled overflows as by the many crevasses occuring at every flood stage.

The minority report by Captain Eads, from which so large quotations have been made in this discussion, was dated one month after the paper now under discussion was read before this Society. Many of the theories and statements of that report are not questioned by any engineer but are foreign to the subject of the present discussion. It has also been stated that this minority report, as presented here, gives the views of the United States Commission, but in the first place but one signature, that of Captain Eads is attached to that minority report, and in the second place, in the discussion as presented, everything not partisan to the ideas of Mr. Corthell, seems to have been omitted in quoting, although in the report itself the views of other members of the commission are given.

The United States Commission, of which General Q. A. Gillmore, M. A. S. C. E. is Chairman, says, in its report :

"The enlargement of the Atchafalaya has steadily progressed since the removal of the raft therefrom by the State of Louisiana. Now it has a capacity of discharge nearly equal to Red River, and affords a line of least resistance for the flow of that stream to the sea. The discharge of Red River into the Mississippi is now small and infrequent. The outlet from the Mississippi to the Atchafalaya is almost constant, and at times very large. The elevation of the water surface at the junction of Old River and the Mississippi, (that is, the old mouth of the Red River,) is almost constantly above that at the head of the Atchafalaya. The difference, on the 13th of last October, being 7.3 feet, in the distance of about five miles. There is a marked tendency to increase this difference of level, and also to enlarge both the communication between the Mississippi and the Atchafalaya, and the Atchafalaya itself."

"We also therefore recommend that at the earliest possible time a continous brush sill be laid across Old River, between Turnbull's Island and the Mississippi, at such point as surveys show to be advisable, with the object of checking the enlargement of the outlet from the Mississippi at that point.

"We recommend that the study of the subject be continued, in order to ascertain, first the expediency of completing the divorce between the Mississippi on the one hand and the Red and Atchafalaya on the other."

"The views of the several members, however, are not in entire accord with respect to the degree of importance which should be attached to the concentration of flood waters by levees as a factor in the plan of improvement of low-water navigation which has received the unanimous preference of the Commission."

"It is considered by all that levees, by confining the flood waters of the river within a comparatively restricted space, do tend, in some degree, to increase the scouring and deepening power of the current. But the extent and potency of their influence in the improvement of the low-water channel, in respect to which, for the purpose of navigation merely, improvement is most needed, and their value, for that purpose, as compared with other methods of improvement, and as compared with their cost, are regarded as subjects requiring further observation and study,

and the accumulation of further and more comprehensive data, before final conclusions can be reached concerning them."

In fact Mr. Corthell and Captain Eads, show, by the extracts quoted from the minority report, that the levees may be broken by extraordinary floods. Our proposition is to prepare for floods and exceptional flood stages by controlled overflows which shall retain the main river at its maximum and regular velocity in times of floods and, by a system of sills or locks, retain the waters of its tributaries at other times.